NAVAL POSTGRADUATE SCHOOL
Monterey, California

AD-A281 035

DTIC
ELECTE
JUL 06 1994
S F D

THESIS

SPREAD SPECTRUM APPLICATIONS
IN
UNMANNED AERIAL VEHICLES

by

Philip K. Bess

June, 1994

Principal Advisor: Michael K. Shields

Approved for public release; distribution is unlimited.

DTIC QUALITY INSPECTED 3

94-20451

94 7 5 106

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE June 1994

3. REPORT TYPE AND DATES COVERED Master's Thesis

4. TITLE AND SUBTITLE
Spread Spectrum Applications in Unmanned Aerial Vehicles

5. FUNDING NUMBERS

6. AUTHOR(S)
Bess, Philip K.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This thesis is part of an ongoing Naval Postgraduate School research project to develop unmanned aerial vehicles (UAVs) using current off the shelf (COTS) technology. This thesis specifically evaluated a spread spectrum UHF data link between a UAV and ground terminal. The command and control (C^2) process and its role as the fundamental premise of the warfare commander were discussed. A review of the Pioneer Remotely Piloted Vehicle (RPV), which gained such wide recognition during Operations Desert Storm and Desert Shield, was provided to the reader for familiarization with the workings of a generic UAV. An investigation of two common spread spectrum techniques and there associated benefits was made. A link budget calculation was made. The choice of a spread spectrum radio transceiver was reviewed. The requirements and design of the UAV and ground terminal antennae were discussed. A link budget analysis was performed. An atmospheric path propagation prediction was performed. The details of an actual flight test and the data gathered were examined. Future changes to enhance the data link performance and increase its capabilities were introduced. The COTS spread spectrum data link will enhance the role of the UAV in its command and control mission for the warfare commander.

14. SUBJECT TERMS
Unmanned Aerial Vehicle, UAV, Data Link, Spread Spectrum, SS, Direct Sequence, DS, Command and Control, C2, Pioneer RPV

15. NUMBER OF PAGES 164

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

DTIC QUALITY ... D 3

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

Approved for public release; distribution is unlimited.

Spread Spectrum Applications in Unmanned Aerial Vehicles

by

Philip K. Bess
Lieutenant, United States Navy
B.S., Southern Illinois University, 1985

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS TECHNOLOGY

from the

NAVAL POSTGRADUATE SCHOOL
June 1994

Author: Philip K. Bess

Approved by: Michael K. Shields, Principal Advisor

Michael G. Sovereign, Associate Advisor

Paul H. Moose, Chairman
Department of Joint Command Control and Communications

ABSTRACT

This thesis is part of an ongoing Naval Postgraduate School research project to develop unmanned aerial vehicles (UAVs) using current off the shelf (COTS) technology. This thesis specifically evaluated a spread spectrum UHF data link between a UAV and ground terminal. The command and control (C^2) process and its role as the fundamental premise of the warfare commander were discussed. A review of the Pioneer Remotely Piloted Vehicle (RPV), which gained such wide recognition during Operations Desert Storm and Desert Shield, was provided to the reader for familiarization with the workings of a generic UAV. An investigation of two common spread spectrum techniques and there associated benefits was made. A link budget calculation was made. The choice of a spread spectrum radio transceiver was reviewed. The requirements and design of the UAV and ground terminal antennae were discussed. A link budget analysis was performed. An atmospheric path propagation prediction was performed. The details of an actual flight test and the data gathered were examined. Future changes to enhance the data link performance and increase its capabilities were introduced. The COTS spread spectrum data link will enhance the role of the UAV in its command and control mission for the warfare commander.

Accesion For

NTIS CRA&I ✓
DTIC TAB
Unannounced
Justification

By
Distribution /

Availability Codes

Dist	Avail and / or Special
A-1	

TABLE OF CONTENTS

ACKNOWLEDGEMENT

I wish to extend my deepest thanks to my loving wife and sons, for their support and encouragement throughout this endeavor. I thank my advisor and mentor Mike Shields for providing the inspiration for this project. I thank Art Hoffman, WA6TVN, for sharing his time, expertise, patience and friendship. I would also like to thank Rick Howard, Don Meeks, Ken Davidson and Keith Jones, for without their support, this project would not have been possible.

I. INTRODUCTION

This thesis is part of an ongoing Naval Postgraduate School research project to develop unmanned aerial vehicles (UAVs) using current off the shelf (COTS) technology. These vehicles will provide proof of concept models for industry to augment the current force assets in a cost effective manner. This thesis specifically evaluates a spread spectrum data link between a UAV and ground terminal. The COTS spread spectrum data link will enhance the role of the UAV in its command and control mission for the warfare commander.

The use of a COTS spread spectrum datalink that will convey navigation, control and payload data between a UAV and an associated ground control station is evaluated in this thesis. Chapter II provides the reader with an outline of the command and control process (C^2). Formal, as well as intuitive definitions are presented to assist the reader in establishing a solid foundation in C^2. This knowledge of the C^2 process will reveal that C^2 itself, is not just a tool of the warfare commander, but a fundamental premise of the commander's very existence. The C^2 process model is covered in detail in order to reveal how all elements within and outside of a commander's particular environment influence the decision making process that generates force orders. Given the process that a commander uses to evaluate organic and non-organic information, specific information needs are addressed. These needs are couched in the commander's battlefield perspective. The information needs will vary from scenario to scenario. Particular battlefield functions of the commander including situation development, target development and battle damage assessment (BDA) are covered. Chapter III describes what UAVs are, their mission, performance, and the 1993 Department of Defense (DoD) Master Plan for acquisition of various UAV projects. Chapter IV selects a particular UAV, the Pioneer Remotely Piloted Vehicle (RPV), which gained such wide recognition during Operations Desert Storm and Desert Shield, to provide the reader with a familiarization with the operations of a combat tested UAV. Chapter V provides background on spread spectrum communications. Two common spread spectrum encoding techniques and the associated benefits are presented. Chapter VI discusses the development of a spread spectrum data link for a current Naval Postgraduate School project. The computer interfaces for both the UAV and the ground terminals are discussed. The choice of a spread spectrum radio transceiver is reviewed. The requirements and design of the UAV and ground terminal antennae are discussed. A link budget analysis is performed. Chapter VII describes the testing and evaluation of the data link. The bench testing of the radio transceiver and the installation of the data link hardware in the UAV are discussed. An atmospheric path propagation prediction is performed. The details of an actual flight test and the data gathered is examined. Chapter VIII draws conclusions about how the UAV's spread spectrum data link can improve C^2. Future changes to enhance performance and increase the data link capabilities are discussed.

II. COMMAND AND CONTROL

To develop an intuitive feel for the nature of command and control (C^2), the following account is provided. Imagine yourself in a position comparable to that faced by General Norman Schwarzkopf in the war with Iraq. You're in charge of and responsible for the coalition forces from eighteen of more nations who face the forces of Saddam Hussein. These forces speak different languages, fight with different tactics, and in some cases harbor mutual and ancient enmities. You must direct all these forces and, indeed, the whole war from within a command post that gives you and your staff at least the appearance of protection and that houses the technology that makes it possible for you to know what is happening on the far-flung fields of battle. Should all the radar screens and television screens in your command post suddenly go blank and all the radios silent, you would find yourself fighting blind, with little idea of what your forces, let alone the enemy's forces, were doing. At that point you would be justified in saying your command and control process had failed, even though some part of the process might be surviving in the shape of plans formed and sent to your forces before the battle began. Had those plans allowed for the possibility of catastrophic system failure, giving operational control to commanders on the scene if communications failed, perhaps not all would be lost. Of course, specific operational plans established before the battle began would soon be of little value since, unless adapted to the rapidly changing conditions on the battlefield, they could quickly become counterproductive. If you can empathize with the plight of a commander in such a situation, you can understand the critical importance of strong command and control. Fortunately, from the perspective of the United States and its coalition allies, it was Saddam Hussein whose command and control failed in 1991, and whose forces ended up flailing impotently in the darkness. (Coakley, 1992, pp. 3-4)

A. DEFINITION

Command and control involves the complex collection of functions (processes) and systems a warfare commander draws upon to arrive at decisions, and to insure that those decisions are carried out in the form of orders and directives. Thus, the acronym C^2 may be used to refer to anything from information in sophisticated communications and computer equipment, to the commander's own mind. The latter involves education, training, experience, intelligence, and other aspects of cognition. Many derivatives of command and control (C^2) such as command, control, and communications (C^3); command, control, communications, and computers (C^4); command, control, communications, computers, and intelligence (C^4I); command, control, communications, computers, intelligence, and interoperability (C^4I^2) exist today. An in depth study reveals that there are actually many more derivatives, virtually C^iI^n. Currently, the phrase "C^4I For The Warrior", is commonly used widely in the defense arena to encompass all of the derivatives of command and control. For the purpose of this thesis, all of these acronyms are synonymous.

The Department of Defense (DoD) defines command and control as:

> The exercise of authority and direction by a purposely designated commander over assigned forces in the accomplishment of the mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission (J.C.S., 1987, p. 77).

The sole purpose of the command and control function is to implement the commander's will in pursuit of the unit's objective. The ultimate measure of effectiveness of command and control is whether the friendly force operates more efficiently and more quickly than the enemy. The essence of command and control is threefold: information, systematic procedures, and communications. Decisions are based on the information available. Systematic procedures insure that all available information from all sources is properly considered in making decisions. Communications are required to provide the information and to transmit the resulting orders. The is a continual process. The commander monitors the execution of his orders (and the evolving friendly and enemy battlefield situation) through the receipt of follow-on information (via all available communication means), and uses this information in re-confirming or modifying his decisions and orders. Thus, the commander commands and controls operations in the accomplishment of his mission by a continuous cycle of incoming information, systematic assessment, decisions, orders, and monitoring. (MORS, 1993, p. 2-2)

B. THE C^2 PROCESS MODEL

Dr. Joel S. Lawson, Sr., Naval Electronic Systems Command, proposed a C^2 process model as shown in Figure 1. The Lawson model accommodates five functions: sense,

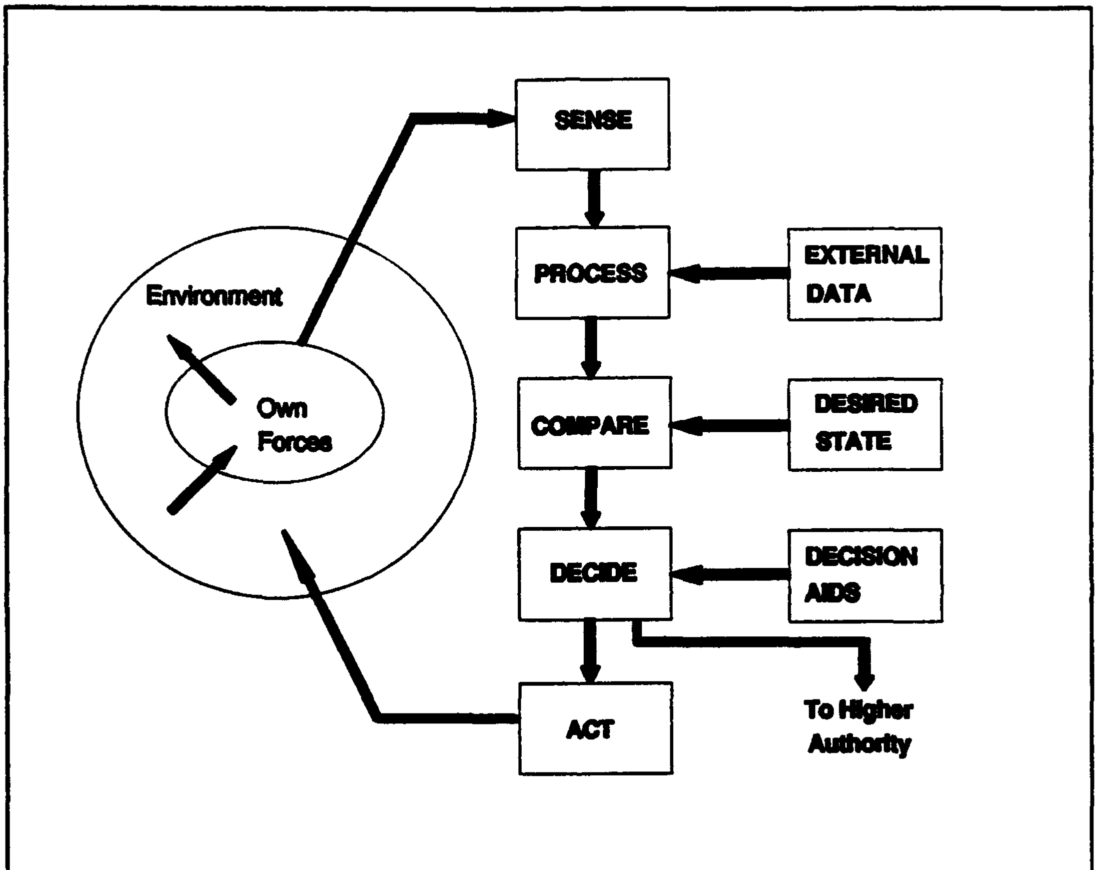


Figure 1. Lawson's model of the C^2 process (Coakley, 1992, p. 32)

process, compare, decide, and act. The sense function corresponds to all data-gathering activities (radar sites, forward observers, photo reconnaissance systems, etc). It gathers data on the environment - the world "out there," including friendly and enemy forces, allied forces, terrain, weather, and so on. The process function draws together and correlates the data to give the commander meaningful information about the environment.

External data, not directly from the environment, may be used to augment the "raw" data gathered in the sense process. This may include intelligence analyses indicating patterns representative of the division headquarters for example. The compare function compares the existing state of the environment (the relative strengths, weaknesses, positions, etc.) with the desired state (the commander's view of what the state of the environment should be). Based upon this comparison, the decide function chooses among available courses of action to move the existing state to the desired state. The act function executes that decision and translates it into action in the form of a directive or order. (Coakley, 1992, pp. 32-33)

Working with a similar C^2 model, Colonel John Boyd, a pilot and combat theorist influential in the so-called Military Reform movement of the late 1970s and 1980s, combined what he knew of aerial warfare with C^2 lessons gleaned from military history to conclude that the key to military victory - regardless of the relative sizes of the opposing forces - is "getting inside" the enemy's decision cycle or C^2 process. (Orr, 1983, p. 19) In other words, whether two forces are engaged in a dogfight with airplanes or a major ground battle, the way to win is to work through the sequence of functions that constitute C^2 faster than the enemy does. In the words of the U.S. Marine Corps' manual *Warfighting*, "Whoever can make and implement his decisions consistently faster gains a tremendous, often decisive advantage (U.S.MC, 1989, p. 69). Having faster C^2 processes allows us time to figure out what enemy commanders are trying to do, and time to cut off their opportunities for doing those things. It allows us to determine what indicators enemy commanders will key on, so we can manipulate those indicators to mislead the enemy. In short, a faster C^2 decision process is the key to affecting the enemy's C^2 decision process. This is what military briefers meant when, during the 1991 Gulf War, they spoke of "getting inside the enemy's decision cycle." (Coakley, 1992, p. 33)

Lieutenant General Raymond B. Furlong wrote,

> Our object in war of strategy is the behavior of a limited number of people. We wish to conduct our affairs in such a way that these people will act in a way that we prefer - our goal in strategy is to influence human behavior in a way favorable to our objectives. I suggest, then, that our strategies ought to seek this as their principle object - the mind of the opposing commander. (Coakley, 1992, p. 34)

In order to favorably influence the outcomes of a battle, the warfare commander must get into the opposing commander's "mind" or C^2 loop. In ancient warfare, the commander's "mind" was the core of a force's C^2. Alexander the Great for example, would rely largely on his own observations and knowledge of the enemy, his own experience in war, and his own genius in formulating his battle plans. Gradually, though, the increased scale and complexity of war, abetted, perhaps, by a norm of commanders less gifted than Alexander, caused C^2 functions to be externalized in the form of staffs. (Coakley, 1992, p. 34) Therefore, obtaining and processing the information as quickly as possible, ideally in real time as the actions take place, allows a commander to direct forces quicker, and therefore effect the battle or engagement in a desired manner.

C. THE WARFARE COMMANDER'S INFORMATION NEEDS

Some 2,600 years ago, Sun Tzu wrote,

> If you know the enemy and know yourself, you need not fear the result of a hundred battles. If you know yourself, but not the enemy, for every victory gained

you will also suffer a defeat. If you know neither the enemy nor yourself, you will succumb in every battle. (Giles, 1944, p. 51)

Information is at least as critical to today's commanders as it was to those of Sun Tzu's day. Dr. Eberhardt Rechtin describe today's naval battle group as "a disturbed offense/defense tied together by an information network." (Rechtin, 1984, p. 12) He goes on to say, "Information is going to be so important in future conflicts that it may well determine the outcomes." (Rechtin, 1984, p. 21) Ensuring the proper flow of critical information among friendly forces is, therefore, an essential C^2 function. And interrupting the enemy's information flow is just as important. (Coakley, 1992, pp. 13-14)

While the face of war has changed considerably in the intervening centuries, C^2 is still information intensive. Commanders need information about the enemy, about the environment in which an encounter may take place, and about the status and the capabilities of their own forces. They need information about objectives; not only must they be clear about their own, but they must know those of their superiors and, ultimately, those of the nation. They need a sense of what is possible; a data bank of options based on their own knowledge of history, their training and experience, the advice of their staffs, and any other available sources. They want to know what has been tried in comparable situations, what has worked and what has not. Once a commander's decision is made, it takes the form of an order. Orders are also information, information about what is expected of each player in the operation. When the action begins, the commander needs information in the form of feedback. Is the plan working? How can it be modified? (Coakley, 1992, p. 13)

Commanders think in terms of the time and space necessary to defeat enemy forces in place, before it becomes necessary to fight directly those which follow. Thus they view the battlefield in terms of areas. One in which they must exert influence immediately, for current operations. And the other, in which they are interested, because enemy forces there threaten their operations at a future time. Areas of operation and interest vary with mission, enemy, terrain, weather, troop availability, and mobility of friendly, as well as enemy forces. Areas of operation and interest generate the commander's information requirements. (MORS, 1993, p. 1-2)

The specific type of threat forces, targets, and nodes about which information is needed, will vary, depending on the specific battlefield and operational situation. This information will support:

- Close-in operations: by the defeating the enemy forces with direct contact.
- Deep operations: by delaying and disorganizing reinforcing elements, denying the introduction of follow-on forces, and interdicting, and disrupting approach routes.
- Rear operations: by retaining freedom of action in the friendly rear area. (MORS, 1993, p. 1-7)

To develop the battlefield perception, the commander has many information needs. These needs include: timely information to all echelons regarding information on mobile targets; virtually near-real-time imagery for confirmation of selected targets detected by non-imaging means; "quick-fire" channels to tactical air support, artillery, and air defense systems, along with procedures for rapid engagement of command designated high payoff targets with previously designated guidelines. The commander requires all of these in an accurate, timely manner. (MORS, 1993, p. 1-4)

D. BATTLEFIELD FUNCTIONS

1. Situation Assessment

Situation assessment is the process of producing a description of enemy force dispositions on the battlefield in terms of location, size, type, direction and rate of movement, and activity. This process is based on an analysis of intelligence holdings which are continuously updated through the collection and processing of information. Situation assessment provides the commander with the foundation for decisions on matters pertinent to their area of operations. It also provides an assessment of the potential impact of activities and events in his area of interest. It assists in answering the three key questions: What is happening? What does it mean? What should be done about it? The intelligence information developed is used by the commander and their staff to assess the enemy's capabilities and intentions and to guide friendly planning activities. Timely and accurate situation assessment provides the foundation for an effective estimate of the situation, and the projection of enemy intentions in sufficient time to permit the commander to select the most effective course of action. Thus, situation assessment supports other functions. (MORS, 1993, p. 5-2)

2. Threat Assessment

Based on situation assessment, threat assessment is the process of providing combat information, targeting data, and correlated targeting information. It provides the commander with timely and accurate location of enemy weapons systems, units and activities which may impact on current or projected operations. Targeting data must be sufficiently accurate to support effective attack by fire, maneuver, or electronic means. (MORS, 1993, p. 5-3)

Threat assessment provides direct and correlated targeting information which meets the commander's target selection criteria. Threat assessment provides the commander with timely and accurate location data on enemy weapons systems, units, activities, or physical features which may impact on his current or projected operations. The commander establishes criteria for the target information which must be provided immediately to the supporting fire support system(s). Threat assessment may encompass both target analysis and target acquisition. Target analysis is the examination of potential targets and includes post-attack analysis to determine the need to re-attack the target(s). The determination is based on the extent to which the attack achieved the commander's objective(s), e.g., delay, disrupt, channelize, or destroy enemy forces. The post-attack target analysis effort supports the battle damage assessment (BDA) function. (MORS, 1993, p. 5-3)

Situation assessment and threat assessment are distinct tasks, however, they must be integrated totally to provide an accurate picture of the battlefield. The key is for the commander to have a timely and accurate visual and mental perception of his battlefield, i.e., of his area of operations/interest. He must have, for example, an appreciation of the total number and type of enemy forces and weapons systems on his battlefield, including special weapons and units (e.g., nuclear, biological, chemical capable delivery systems, special operations forces, commando forces). He must also have an appreciation of the fraction of forces/weapons already located and yet to be located. The ability of any RSTA system, or combination of RSTA systems, to provide the commander a complete, timely, and accurate visual and mental perception of their respective battlefields is a bottom line measure of effectiveness of the RSTA system or systems. Target acquisition, requires the timely detection, identification, and location of targets in sufficient detail and location accuracy to permit effective attack by friendly weapons systems. (MORS, 1993, p. 5-4)

3. Battle Damage Assessment

Battle damage assessment (BDA) is the determination of the effect of attacks on targets. The BDA function is more than simply a determination of the effect on targets, e.g., whether a target was destroyed. It is the determination of the extent to which the attack achieved the commander's objective(s) and the need to re-attack the targets. For example, if the purpose in destroying a bridge is to interdict the movement of enemy forces; it is not enough to know that the bridge has been destroyed. The commander must also know whether or not the enemy forces have been interdicted or are using an alternate route or means to cross the obstacle and continue their movement. If so, another attack will be required on the forces or on the alternate route/means. (MORS, 1993, p. 5-5)

To stay inside the enemy's decision cycle, the commander will employ a decide, detect, and deliver philosophy. The commander will project friendly operations and anticipate threat responses. This decide, detect, re-decide, deliver philosophy provides another opportunity for the commander to render a decision based on the situation and threat existing at that time. The bottom line is that the process is designed to be "proactive" as opposed to reactive. The planning, decisions, actions, tasking, and execution must all occur in real or near real time. (MORS, 1993, p. 1-9)

The commander uses sense, process, compare, decide, and act as micro steps of his own C^2 process. Situation assessment, threat assessment and BDA can be thought of as macro steps of the overall C^2 warfare process. The situation assessment provides organic and non-organic information to the commander as well as what the big overall theater picture or guidance suggests. The threat assessment provides a much more detailed, in theater perspective of what the commander faces in order to maintain or accomplish the overall guidance. BDA provides quick feedback to the commander assessing the effects of his latest actions. When mapping situation assessment, threat assessment and BDA back to Lawson's C^2 model, its hard to delineate clear boundaries between these functions. What's most important to recognize, is that C^2 is a continual, dynamic process. The most effective commanders realize their role within and relationship to the C^2 process.

III. THE UNMANNED AERIAL VEHICLE

The unmanned aerial vehicle (UAV) system can enhance the commander's visual and mental perception of the battlefield by providing information concerning the disposition of enemy force composition and locations, and the numbers and locations of specific targets for attack. (MORS, 1993, p. 1-3) The UAV is defined as an aerial vehicle that does not carry a human operator and can be flown autonomously or be remotely piloted. It can be expendable or recoverable, and can carry lethal or non-lethal payloads. This chapter will cover the UAV Master Plan, program history, UAV requirements, categories of UAVs and significant projects.

UAVs provide an alternative means to manned aircraft and to satellites for gathering information for the warfare commander. UAVs may be cheaper to operate than manned aircraft or satellite systems. UAVs require less training to operate than do manned aircraft. UAV systems are much more simplistic than satellite systems when considering the aspects of launch, operation and support.

A. MASTER PLAN

UAVs can make significant contributions to the warfighting capability of operational forces. They greatly improve the quality and timeliness of battlefield information while reducing the risk of capture or loss of troops, thus allowing more rapid and better informed decision making by battlefield commanders. While reconnaissance, surveillance, and target acquisition (RSTA) are the premier missions of UAVs, they can also provide substantial capabilities in electronic warfare (EW), electronic support measures (ESM), command and control (C^2), and special operations mission areas. UAVs are a particularly valuable adjunct to the Service's aviation communities. They can readily perform a multitude of inherently hazardous missions: those in contaminated environments, those with extremely long flight times, and those with unacceptable political risks for manned aircraft. Allotting these dirty, dull and dangerous missions to UAVs saves the of manned aircraft for missions requiring a human pilot onboard. (UAVJPO, 1993, p. 1)

In 1988 Congress recognized the need for common and interoperable systems and zeroed separate service funding for UAVs. Congress directed the Department of Defense (DoD) to consolidate the management of DoD nonlethal UAV programs and to prepare an annual UAV Master Plan. DoD responded by forming an Executive Committee (EXCOM), designating the United States Navy as Executive Service, forming a UAV Joint Project Office (UAV JPO) and submitting the first UAV Master Plan to Congress. The UAV Master Plan provides requirements, program plans, management and acquisition strategies for nonlethal UAVs. Lethal UAV programs are addressed in the DoD Standoff Weapons Master Plan. (UAVJPO, 1993, p. 1)

Further refining the program in 1991, DoD dissolved the UAV EXCOM and designated UAVs a major defense acquisition program. The first Defense Acquisition Board (DAB) review was held on 10 December 1991. The Acquisition Decision Memorandum (ADM) resulting from the DAB approved the designation of the Close Range (CR), Short Range (SR), and Medium Range (MR) UAVs as individual

Acquisition Category (ACAT) 1D programs. The Maritime Vertical Takeoff and Landing System phase I, known as MAVU.S., at sea operational experiment was completed in 1992 and the U.S. Navy approved the Vertical Takeoff and Landing (VTOL) Operational Requirements Document (ORD). (UAVJPO, 1993, p. 3)

The UAV JPO's mission is to expeditiously field quality UAV systems which provide a significant tactical advantage to operational commanders. It is the DoD "center of excellence" for UAVs and provides advice and guidance to other federal agencies interested in employing UAVs. It is anticipated that through the 1990s the civil (i.e., nonmilitary federal, state, and local government) and commercial applications of UAVs will grow substantially. The UAV JPO intends to capitalize on the synergism among these three markets and achieve the benefits of costs savings through combined acquisitions, expanded use of commercial specifications and standards, fostering of technological innovation and new applications, and strengthening of our industrial technology and production base. The UAV JPO is guided by the following management principles:

- Continuously improve the process to develop, procure and support UAVs
- Develop an affordable family of UAV systems that are interoperable
- Proactively foster the use of nondevelopmental items (NDI) and commonality in order to achieve the lowest operational cost
- Continuously address and support the expectations of all UAV customers, and consider the users as partners with the UAV JPO (UAVJPO, 1993, p. 2)

In 1990, the U.S. Navy transitioned to the Program Executive Officer (PEO) structure. The UAV JPO became part of the PEO for Cruise Missiles and Unmanned Aerial Vehicles (PEOCU), which has acquisition management responsibility for naval cruise missiles, naval targets, and Joint Service UAVs. By using strategic planning, the PEO encompasses obligations to:

- Expand and strengthen working relationships with their customers and stockholders in order to promote open communication that is responsive to customer expectations.
- Develop affordable, interoperable families of cruise missiles, targets and UAV systems. Continuously improve the processes to design, develop, test, produce, deploy and support all current and future versions of these systems.
- Actively pursue the use of NDI and interoperability and commonality (I&C) in order to achieve the optimal trades between system ownership costs and operational performance.
- Treat people as their primary and most valued asset. Lead by searching out challenging opportunities for people to change, grow, innovate, and improve their skills. (UAVJPO, 1993, p. 12)

The UAV Master Plan serves as a vehicle for the UAV JPO to provide advice and guidance to the Services and other federal agencies interested in employing UAVs. The UAV Master Plan provides requirements, program plans, management and acquisition strategies for nonlethal UAVs. It is updated annually.

B. REQUIREMENTS

UAV requirements are delineated by Mission Need Statements (MNSs). These MNS include both categories and capabilities of the UAVs. This section discusses UAV requirements.

MNS for four categories of UAV capabilities have been validated by the Chairman of the Joint Requirements Oversight Council (JROC). These categories are the Close (CR), Short (SR), Medium and Endurance categories. A summary of the Mission Need Statement is included in Figure 2. CR capabilities address the needs of lower level tactical units such as U.S. Army divisions and brigades/battalions and U.S. Marine Corps battalions/companies for a capability to investigate activities within their local area of

	CLOSE	SHORT	MEDIUM	ENDURANCE
OPERATIONAL NEEDS	RS TA TS EW MET NBC	RS TA TS. MET NBC C2. EW	PRE-AND POST-STRIKE RECONNAISSANCE TA	RS TA C2. MET NBC SIGINT EW. SPECIAL OPS
LAUNCH AND RECOVERY	LAND/SHIPBOARD	LAND/SHIPBOARD	AIR/LAND	NOT SPECIFIED
RADIUS OF ACTION	NONE STATED	150 KM BEYOND FORWARD LINE OF OWN TROOPS (FLOT)	[illegible] KM	CLASSIFIED
SPEED	NOT SPECIFIED	DASH >110 KNOTS CRUISE < [illegible] KNOTS	[illegible] KNOTS < [illegible] FT [illegible] MACH > [illegible] FT	NOT SPECIFIED
ENDURANCE	24 HRS CONTINUOUS COVERAGE	8 TO 12 HRS	2 HRS	24 HRS ON STATION
INFORMATION TIMELINESS	NEAR-REAL-TIME	NEAR-REAL-TIME	NEAR-REAL-TIME RECORDED	NEAR-REAL-TIME
SENSOR TYPE	DAY/NIGHT IMAGING* EW NBC	DAY/NIGHT IMAGING* DATA RELAY COMM RELAY RADAR SIGINT MET MASINT TD EW	DAY/NIGHT IMAGING* SIGINT MET. EW	SIGINT MET COMM RELAY. DATA RELAY. NBC IMAGING MASINT EW
AIR VEHICLE CONTROL	NONE STATED	PRE-PROGRAMMED/ REMOTE	PRE-PROGRAMMED	PRE-PROGRAMMED/ REMOTE
GROUND STATION	VEHICLE & SHIP	VEHICLE & SHIP	JSIPS (PROCESSING)	VEHICLE & SHIP
DATA LINK	WORLD WIDE PEACE TIME USAGE. ANTI-JAM CAPABILITY	WORLD WIDE PEACE TIME USAGE ANTI-JAM CAPABILITY	JSIPS INTEROPERABLE WORLD WIDE PEACE TIME USAGE. ANTI-JAM CAPABILITY	WORLD WIDE PEACE TIME USAGE. ANTI-JAM CAPABILITY
CREW SIZE	MINIMUM	MINIMUM	MINIMUM	MINIMUM
SERVICE NEED REQUIREMENT	USA. USN. USMC	USA. USN. USMC	USN. USAF. USMC	USA. USN. USMC

* Baseline Payload Capability

LEGEND
C2 - COMMAND AND CONTROL
EW - ELECTRONIC WARFARE
JSIPS - JOINT SERVICE IMAGERY PROCESSING SYSTEM
MASINT - MEASUREMENT AND SIGNATURES INTELLIGENCE
MET - METEOROLOGY
NBC - NUCLEAR, BIOLOGICAL and CHEMICAL RECONNAISSANCE
RS - RECONNAISSANCE AND SURVEILLANCE
SIGINT - SIGNALS INTELLIGENCE
TA - TARGET ACQUISITION
TS - TARGET SPOTTING
TD - TARGET DESIGNATOR

Figure 2. MNS Summary (UAVJPO, 1993, p. 13)

interest, approximately 30 kilometers (km) beyond the forward line of own troops (FLOT). Systems must be easy to launch, operate and recover; require minimum manpower, training and logistics; and be relatively inexpensive.

SR capabilities support U.S. Army division through echelons above corps level and U.S. Marine Corps Air-Ground Task Force (MAGTF) level. Enemy activities out to a range of 150 km or more beyond the FLOT or datum point are a focus of SR activities. These UAV systems are more robust and sophisticated, can carry a wider variety of payloads, and can perform more missions than CR systems.

MR capabilities address the need to provide pre- and post-strike reconnaissance of heavily defended targets. The MR would augment manned reconnaissance platforms by providing high quality, near-real-time imagery out to a range of 650 km beyond the FLOT. They differ from other UAV capabilities in that the vehicle is designed to fly at high subsonic speeds and spend relatively small amounts of time over areas of interest.

The fourth category of UAV is known as the Endurance. The Endurance will have capabilities that can respond to a wide variety of mission needs and fulfill the requirement to carry many types of payloads. Endurance systems are characterized by times of flight measured in days and very great ranges and altitudes of flight. (UAVJPO, 1993, pp. 13-14)

C. PROGRAMS

This section will cover the CR, SR, MR and Endurance programs. Significant projects within each category will be addressed. The projects addressed will include information about the vehicle characteristics, capabilities and project status.

1. Close Range

The CR acquisition strategy dictates the procurement of a cost effective system of integrated COTS technologies with a high degree of interop..bility and commonality (I & C) with the Short Range (SR) system, as the baseline for the family of UAVs. The CR system will provide near-real-time RSTA capabilities out to 30 km beyond the FLOT that meet the requirements of U.S. Army and U.S. Marine Corps commanders at division and subordinate levels of command. The CR concept, system requirements, and acquisition/risk management planning have been significantly influenced by SR progress, formal studies, experimentation with existing domestic and foreign systems, budget realities and lessons learned during Desert Storm. (UAVJPO, 1993, pp. 26-30)

The CR system equipment to be fielded with the U.S. Marine Corps to support the MAGTF consists of a small UAV with a day/night sensor and meteorological sensors controllable from a portable ground control station (GCS). This system will be operable by two service personnel, and will be transported on a single high mobility multipurpose wheeled vehicle (HMMWV) and standard trailer. The system will also be fielded with the U.S. Army at the division and brigade level as the launch/recovery section and will be augmented with a GCS and associated hardware from the SR system. This will provide maximum C^3I commonality and interoperability to support the U.S. Army's battlefield operators. The employment concept for this augmented system is to perform launch, recovery, handling, and initial/terminal flight operation from rear areas, while mission planning/control and data distribution will be handled in forward areas. (UAVJPO, 1993, pp. 26-30) One significant CR project is the FQM-151A Pointer. The following paragraphs review the Pointer system.

The Pointer is a very low cost, hand-launched, battery powered UAV. Both a black and white and color television camera are available as payloads. Pointer is two man backpackable in hard-shell containers attached to military issue pack frames. The air vehicle container weighs 45 pounds and the ground control unit (GCU) weighs 50 pounds. A new softpack for the air vehicle will weigh 23 pounds and be air-droppable in parachute operations. The GCU controls the air vehicle, displays and records air vehicle video imagery, and records narrative provided by a ground observer. The air vehicle is quickly assembled from six sections, has a nine foot wingspan and is six feet long. Launch weight is presently nine pounds with new replacement air vehicles weighing only eight pounds.

The Pointer is launched by hand with a throwing maneuver much the same as a kite is launched. Recovery is executed by a deep-stall maneuver to a soft landing in a flat attitude. Pointer can be prepared for launch in less than five minutes by two personnel. The air vehicle presently has a range of 5 km and a flight duration in excess of one hour. Optimal operating altitude for the air vehicle is typically 200 to 500 feet above ground level (AGL). One pointer system normally includes four air vehicles and two GCUs. The mission of Pointer is reconnaissance and surveillance for lower-level ground combat units (e.g., infantry companies and battalions) within their local areas of responsibility. Only brief orientation training is required to qualify Pointer system operators. No unique educational background, formal school training, extensive military skills or uncommon physical skills are required. (UAVJPO, 1993, pp. 48-50) The Pointer program was terminated in 1993.

2. Short Range

The SR system is the developmental baseline for the family (i.e., SR, CR, VTOL and Endurance) of UAVs. SR will provide near-real-time RSTA to U.S. Army echelons above corps (EAC), divisions and U.S. Marine Corps expeditionary brigades out to 150 km beyond FLOT, day or night, and in limited adverse weather conditions. SR is intended for employment in environments where immediate information feedback is needed, manned aircraft are unavailable, or excessive risk or other conditions render use of manned aircraft less than prudent. The SR acquisition strategy ensures interoperability and maximizes commonality, including the fielding and evaluation of an initial baseline configuration, followed by block upgrades to meet the full operational requirements. A modular approach incorporating standard architecture facilities upgrades and provides a flexible baseline for other systems. The SR system takes maximum advantage of COTS technologies. (UAVJPO, 1993, p. 21-25) Four SR projects include the EXDRONE, Pioneer, MAVUS and TRUS. The later two are of the vertical takeoff and landing (VTOL) category. These four projects are discussed in the paragraphs that follow.

The BQM-147A EXDRONE is a delta wing air vehicle powered by a small two-cycle gasoline engine. The air vehicle can carry a payload of up to 25 pounds, fly at a maximum speed of 100 mph for up to 30 minutes or it can loiter for up to two and a half hours at altitudes up to 10,000 feet. Major components are the fuselage assembly, right and left wing assemblies, payload bay, avionics equipment bay and field installable, canister-packed safety parachute. Each wing contains a fuel cell and lithium battery, and consists of monocoque skin assemblies with a central wood wing rib and one piece blade spar passing through the fuselage and extending into each wing. Skin material consists of three millimeter foam-core molded epoxy fiberglass. The entire system can be transported in a HMMWV.

The ground control subsystem consists of radio control equipment, a data display, and a monitor that shows the video camera image. After launch, control and monitoring of the EXDRONE can be accomplished using the ground control equipment. The ground support subsystem includes support equipment for autopilot programming, payload testing, fueling, and launching of the air vehicle. Launch is accomplished by bungee catapult of the EXDRONE on a three-wheeled dolly and recovery is accomplished on a four point skid system. The air vehicle can also be recovered using a canister-packed safety parachute.

The EXDRONE is launched from a prepared surface by two crew members. Takeoff, climb out and turn to the desired heading is accomplished by radio control. After achieving the desired heading, the EXDRONE is a given radio control command to switch control to the autopilot. The autopilot controls the EXDRONE for the duration of the mission, although ground control can be resumed if desired. The EXDRONE operating area is normally within 50 km of the FLOT. The onboard video camera will provide live color television monitoring of enemy activity within the operating area for a preset time and the EXDRONE will then be recovered. Additionally, the U.S. Marine Corps has an existing requirement to provide tactical ECM support to the MAGTF Commander. The required operational capability (ROC) for the EXDRONE Communication Jammer defines a requirement for a small, low cost, expendable UAV capable of performing communication jamming operations on the enemies' side of the FLOT. The EXDRONE Communications jammer complements ground based ECM systems in the MAGTF. The EXDRONE Communications Jammer program is a U.S. Marine Corps unique program. Because the EXDRONE is expendable, no maintenance above organizational level is required. (UAVJPO, 1993, pp. 46-48) The EXDRONE program was terminated in 1993.

The Pioneer Remotely Piloted Vehicle (RPV) system provides near-real-time RSTA, BDA, and battlefield management within line-of-sight (LOS) of its GCS, day or night. Pioneer can be deployed on land, or from certain naval platforms. Previously, Pioneer was deployed from battleships, but is now deployed from amphibious ships. A Pioneer system consists of five air vehicles, a GCS, a portable control station, two remote receiving sets, and pneumatic or rocket assisted launchers if required. A Pioneer system is transported using two five-ton trucks and two HMMWVs with trailers. Pioneer air vehicles are capable of operating for up to five hours with either day television or night FLIR sensors. Pioneer flies between 1,000 and 13,000 feet above sea level, 60 - 95 knots, and up to 220 km from a GCS. The air vehicle is driven by a pusher propeller and powered by a two-cylinder engine using aviation gas. DoD received an initial inventory of eight Pioneer systems, two systems for the U.S. Navy, three for the U.S. Marine Corps, one for the U.S. Army, one for testing and one for training. A flight crew consists of 4 personnel and requires 16 support personnel. (UAVJPO, 1993, pp. 36-39)

Pioneer was introduced into the force structure in 1986. Since that time, U.S. Navy units have operated from four battleships during five deployments supporting world-wide operations in Africa, Northern Europe, the Northern Atlantic, Korea, the Mediterranean Sea and contingency operations in the Persian Gulf. Marines have supported Weapons and Tactics Instruction and Kernal Blitz exercises as well as supporting the U.S. Customs Service in drug interdiction missions. All three Services operated Pioneer in support of Operation Desert Storm. Since 1986, Pioneer units have flown approximately 6,600 flight hours in 3,100 flights. Pioneer is scheduled to operate through FY98, being gradually replaced by SR systems as they enter the force structure. (UAVJPO, 1993, pp. 36-39)

The VTOL UAV, formerly the Maritime UAV, will provide an organic, unmanned, over the horizon RSTA and ship-self defense capability for expanding battle space of surface combatants. The air vehicle will be capable of VTOL to minimize deck impact and interference with shipboard helicopter operations. The system will conduct extended operations in a maritime environment, during inclement weather and in moderate sea states. The VTOL UAV missions of over the horizon targeting (OTH-T), naval gunfire support (NGFS), battle damage assessment (BDA) and ship classification will generally be performed 80 to 110 nm from the host ship. These missions will task the air vehicle to search a designated area to confirm and more precisely geolocate a suspected target, usually with imagery for positive identification and BDA. The air vehicle will have a cruise speed of 135 knots, an on-station loiter time of 3 hours at 110 nm and a maximum operating altitude of 12,000 feet.

The VTOL UAV system concept focuses on integrating SR UAV system software and hardware into the DDG-51 class destroyer subsystems which will be modified or adapted for the maritime system applications. The air vehicle will carry imaging sensors common with the SR and CR UAV programs and will incorporate the SR video downlink to ensure interoperability. SR system software will be hosted on an existing computer processor in the ship's operations' center to accomplish mission planning, air vehicle control and data exploitation functions. Because of the unique operating environment, the VTOL UAV will require its own launch and recovery equipment. (UAVJPO, 1993, pp. 41-44) Two SR VTOL projects include the MAVUS and TRUS. They are discussed in the following paragraphs.

The CL-227 Maritime Vertical Takeoff and Landing UAV System or MAVUS as it is known, includes a small, compact rotary-wing air vehicle capable of VTOL, hover and forward/reverse flight. The air vehicle carries modular mission payloads weighing up to 100 pounds and flies at speeds from hover to 70 knots. Range is 60 km, maximum attainable altitude is 10,000 feet and flight endurance is up to three hours, depending on payload weight. The air vehicle (nicknamed "Peanut" because of its shape) has a modular body (three modules) which is 5.5 feet high, a rotor diameter of nine feet and a maximum takeoff weight of 440 pounds. The MAVUS is manufactured by Canadian Commercial Corporation. The United States and Canadian Governments have established a project agreement under the Defense Development Sharing Agreement for the development, test and evaluation (DT&E) of a MAVUS onboard a U.S. Navy combatant. The MAVUS I at sea operational experiment has been completed. The U.S. Navy has approved the VTOL ORD. Demonstrations of the MAVUS II at sea automatic launch and recovery as well as the systems integrations of the U.S. Navy standard tactical advanced computer-III

(TAC-III) workstation with the tactical data link (AN/SQR-4) are currently being evaluated. (UAVJPO, 1993, pp. 2 - 6) The final report is due this year.

The Tilt Wing/Rotor UAV System, or TRUS as it is known, is well suited to support the long range and high speeds required for over the OTH-T for ship and missile systems RSTA for U.S. Marine Corps fire support elements. In addition, TRUS will provide a VTOL capability required for small combatant ships operation. The Bell Helicopter Textron Inc. (BHTI) TRUS air vehicle crashed during its early trials. (UAVJPO, 1993, pp. 3 - 6, 43)

The SR program has examined several UAVs and will continue to explore more UAVs within the 150 km range. With the EXDRONE project terminated in 1993, and Pioneer scheduled to terminate in 1998, other conventional takeoff and landing (CTOL) UAVs will continue to be evaluated. While the VTOL projects definitely have a need, funding will dictate the pace of their evaluation and later implementation.

3. Medium Range

The following paragraphs discussed the MR program and one particular project, the Specter. The MR UAV is being developed to perform U.S. Navy, U.S. Marine Corps, and U.S. Air Force reconnaissance missions in the late 1990s and beyond. A complementary asset to manned tactical reconnaissance, it will provide a quick response capability to obtain high quality imagery in high threat environments. The system provides multi-function support to the C^3I operations of Carrier Battle Groups (CVBGs), MAGTFs, and Tactical Air Force (TAF) units, with target acquisition (pre- and post-strike) and BDA being two of its primary missions. Upon creation of the UAV JPO, operational requirements of the individual Services were consolidated into a MNS which was approved in June 1989. The MR UAV will be tasked to collect imagery data on fixed targets/locations at ranges up to 650 km from launch point. The data will be of sufficient resolution and accuracy to support targeting for air and ground delivered weapons and to provide BDA. Its range of operation will be 650 km, with a speed of 0.9 mach, and fly at an altitude of 500 to 40,000 feet AMSL. (UAVJPO, 1993, pp. 31-35)

Typically, the MR UAV will fly high risk missions in heavily defended areas where the severity of the threat makes assigning the mission to manned tactical reconnaissance aircraft undesirable. The MR UAV acquisition strategy emphasizes harmonization of Service requirements and the commonality and standardization of system hardware, software, training and ILS. The system concept focuses on interoperability with Service common mission planning and data exploitation systems. (UAVJPO, 1993, pp. 31-35)

One particular MR project is the BQM-145A Specter. The Specter is built by Teledyne Ryan Aeronautical. The Specter can be launched from the ground or F/A-18 and F-16 aircraft. The Specter carries the Advanced Tactical Air Reconnaissance System (ATARS) sensor suite.

The Specter is autonomous once launched. It uses the same software developed for the Navy-Marine Corps tactical aviation mission planning system and the Air Force's mission support system. Both systems provide a user-friendly mission-planning tool that allows for optimum flight path and payload set-up. Each system uses the appropriate data cartridge, which in turn will be used to load the mission into the

Specter, either via the launch aircraft itself, or directly into the air vehicle's mission computer. Versions of both systems already are in use with the operational forces and the transition should be easy. While ATARS is Specter's designated payload, it can carry other payloads weighing up to 400 pounds: electronic intelligence (ELINT) gathering equipment, communications intelligence (COMINT) gathering equipment, jamming equipment, meteorological and decoy equipment, etc. Its large payload, 5,100 watts of electrical power, and 3,000 BTUs per hour cooling capacity, give it excellent growth potential. Given an airframe designed for a minimum 300 hour service life, it will not be difficult for the user to develop additional uses for this versatile vehicle. Finally, its imagery product is of value to customers other than the tactical reconnaissance community. (Witte, 1993, pp. 83-84)

The MR program has yet to implement a 650 km UAV. The combination of ATARS digital imagery and a real-time data link, together with the Specter's ability to fly low, fast, navigate precisely, and be turned around quickly following mid-air or ground-water recoveries, might have filled the current void for an MR vehicle. The Specter's payload has been cancelled which has halted the development of the vehicle itself.

4. Endurance

The UAV Special Study Group (SSG) Working Group has initiated an effort to consider a requirement for an Endurance UAV that would be responsive to the needs of tactical commanders. The UAV JPO is assisting in the effort. At present the Defense Support Project Office (DSPO) has the responsibility for satisfying the requirements of the Endurance MNS. (UAVJPO, 1993, pp. 50-52)

In summary, the four categories of UAVs were established to fulfill the requirements of the MNS. These categories are primarily arranged by vehicle range and endurance. The mission of each UAV will dictate an appropriate payload. The end result of the UAV mission will be a real-time product for the tactical commander. The possession of this product will improve the commander's C^2 process and positively influence the intended mission outcome.

D. COMMUNICATIONS INTEROPERABILITY

This section addresses the need for the interoperability between UAVs and other DoD communications systems. All UAV ground control stations (GCSs) should be able to control and to receive and exploit mission data from different air vehicles, regardless of the system mix. The UAV JPO is evaluating existing data link communications technology for potential application to the establishment of a common, interoperable data link subsystem for the UAV family. This is challenging since such a data link must first be interoperable with the SR baseline, and all subsequent UAV systems including CR, VTOL and Endurance. (UAVJPO, 1993, pp. 53-57)

A key UAV JPO objective is to minimize the number of new data links required as a result of the UAV integration into the Services' force structure. Therefore, the UAV JPO is evaluating existing data links of the Services' C^3I systems for possible co-use as UAV data links. Scaled down versions of the Joint Tactical Information Distribution System (JTIDS) and/or DoD's Common Data Link (CDL)/ Interoperable Data Link (IDL) equipments have potential for use as UAV data link components. Cooperative UAV JPO evaluation of low cost JTIDS at the JDF continues to assess integrated system functionality. Assuming the concepts of low cost and lightweight JTIDS and CDL/IDL are proven, the JTIDS and the CDL/IDL could be added to the family baseline architecture during future block upgrades. Development of a common UAV family data link subsystem architecture incorporating the SR baseline link, JTIDS, and CDL/IDL as selectable primary and alternate links could provide the communications network needed for the UAV systems interoperability. (UAV JPO, 1993, pp. 53-57)

The advanced technology data links program responds to the need for reliable control and data interchange with future air vehicles and their payloads in increasingly hostile threat environments. Low cost, lightweight, long range data links for the entire spectrum of projected UAV operational environments is the goal. These data links must have *sufficient jam resistance to operate in extremely dense* and hostile (including active jamming) electromagnetic environments. Current data links accomplish this through the use of spread spectrum encoding of the transmitted signal. There must also be data link interoperability among the various categories of UAVs and other battlefield C^3I systems. IDL/CDL, millimeter wave, laser, and ultra-wide band communications offer improved potential in reducing data link signatures, increasing jam resistance, and providing more flexible data bandwidths for advanced sensors. Two transmission methods are being studied: "pure noise" ultra-wide band and optical (laser). Both technologies will be examined during a requirements definition study designed to identify and match proposed future UAV systems' applications with advanced data link component development achievements. Two or more data link designs will be prototyped and tested in a multiphased program with the results providing inputs for use in establishing specifications for a future family of common UAV data link components. (UAVJPO, 1993, pp. 53-57)

It is essential that UAV systems interoperate with other communication systems. The data link is the most critical component for this interoperability. The data link must not only be compatible with other components of the C^2 system, but it must be immune to jamming and undesired exploitation.

E. UAVs IN DESERT STORM

The success of UAVs in Desert Storm affirmed the military Services' commitment to integrate UAV systems into their force structures for a number of missions. In Operation Desert Storm, U.S. commanders operated three types of UAVs that provided real-time imagery. This following paragraphs discuss some lessons learned from the Pointer, EXDRONE and Pioneer.

First deployed in December 1986 aboard the U.S. Navy's battleship *U.S.S. Iowa*, the Pioneer is currently assigned to two ship-deployable U.S. Navy detachments, three U.S. Marine Corps companies, and one U.S. Army platoon, plus testing and training units. Successful deployments have been accomplished by the U.S. Navy aboard battleships, by the U.S. Marine Corps aboard amphibious ships, and on land by the U.S. Army. The high point in Pioneer's operational history was its unprecedented success during Desert Shield/Desert Storm. The U.S. Army, Navy, and Marine Corps commanders lauded the UAV for its effectiveness in the areas of RSTA, naval gunfire support (NGFS), BDA, and as a battlefield management platform. By April 1992, Pioneer systems had flown about

7,000 hours in 3,300 total flights. (Garrison, 1992, p. 3) Six Pioneer UAV systems participated in Operation Desert Storm, three with the 1st MEF, two with the U.S. Navy battleships *U.S.S. Missouri* and *U.S.S. Wisconsin*, and one with the U.S. Army VII Corps. The Pioneer system provided near-real-time reconnaissance, surveillance, target acquisition and spotting, and BDA during both day and night operations. Each Pioneer system supported multiple units and performed different reconnaissance missions on each flight. Airborne Pioneers were often tasked to verify radar contacts generated by the Joint Surveillance and Target Attack Radar System (JSTARS) aircraft. JSTARS served as a wide-area alerting sensor for high priority mobile targets and Pioneer acted as the confirming sensor. One Pioneer unit actually tracked an Iraqi Free Rocket Over Ground (FROG-7) missile launcher from its hiding place in a fire station in Kuwait all the way down to the Saudi border where the FROG-7 set up and fired into Saudi Arabia. Pioneer also proved to be survivable. While manned aircraft tended to fly mostly at medium altitudes for enhanced survivability, Pioneer flew all missions below 5,000 feet AGL and within the envelope of optically directed guns and IR missiles.

In 302 sorties and 1050 flight hours, only one Pioneer was downed as a result of Iraqi air defenses. Eighteen others were lost due to human error, material fatigue and equipment failure. Airspace integration and command and control of Pioneer operations were superb. Each Service chose to handle flight coordination of Pioneer missions in concert with manned aircraft missions in Service unique fashions. The concerns raised prior to Desert Storm as to the "mixibility" of UAVs and manned aircraft were shown to be solvable. Because Pioneer was only an interim SR system, it had to be logistically entirely by an in-theater contractor representative, AAI Incorporated of Hunt Valley, Maryland. (UAVJPO, 1992, pp. 59-62)

Pioneer does have some limitations, which were clearly demonstrated in Desert Storm. When operated as a Corps level asset with the U.S. Army VII Corps, Pioneer did not have the range and endurance required for all ground operations. Seventh Corps clearly needed a UAV system with a radius of action of about 300 km using an airborne data relay plus a time on station in excess of four hours at maximum range. Pioneer range was generally satisfactory for the U.S. Navy and U.S. Marine Corps, but additional endurance would have been welcomed. At night, mission endurance was further reduced in some cases by an inadequate FLIR cooling system. Pioneer's launch and recovery characteristics were also a major limitation. Both the U.S. Army and U.S. Marine Corps had to construct UAV airfields on short notice to support the ground force operations. This required the diversion of critical engineer resources from combat operations. Aboard ship, use of a net recovery system was manpower intensive, often damaged the air vehicle and restricted the use of topside deckspace on the host ships. Pioneer's use of 100 octane AVGAS was a logistic limitation because it is not in the U.S. military supply system, and could only be obtained in Bahrain. The next closest source was Greece. Also, the lack of a laser target designator capability for Pioneer precluded its use in the laser spotting of targets. With a great number of laser guided munitions present on the battlefield, a laser target designator for Pioneer could have assisted in the attack of high value, mobile targets. Multisite EMI between Pioneer systems and other high power microwave emissions were suspected as a possible contribution to the vehicle losses. Finally, imagery dissemination from the Pioneer GCS to other units was unsatisfactory. In some cases, video tapes of the imagery were made in the GCS and delivered to other units. Upon receipt of the video tapes, however, the units failed to view the tapes until days later. The Pioneer remote receiving system units were deficient in both range and data dissemination capability. (UAVJPO, 1992, pp. 60-61)

Two types of CR category UAVs were deployed in Desert Storm. Five FQM-151A Pointer systems were provided to the U.S. Army and U.S. Marine Corps units and one BQM-147A EXDRONE system was provided to the U.S. Marine Corps. The CR systems performed reconnaissance and target acquisition using high resolution imagery sufficient to distinguish friendly from enemy forces. They operated in a range of 3 - 60 km. A GPS type accuracy at all ranges was sufficient to support rapid engagement by fire support elements without the need for round by round adjustment. Launch and recovery was performed in unimproved, clear areas in high wind conditions. Operators with an initial low degree of skill and training became adequately proficient in the UAV's operations with only on-the-job training. (UAVJPO, 1992, p. 61)

Neither MR nor Endurance category UAVs were used in Desert Storm. One broad conclusion drawn from Operation Desert Storm is that although the concept of a family of UAVs is valid, varying requirements call for a degree of specialization among UAV systems based on mission, Service, and echelon of command supported. Ultimately, only the air vehicle portion of a UAV system needs to possess a very high degree of specialization, primarily due to aerodynamic performance requirements. Other elements of UAV systems can be common among members of the family of UAVs. (UAVJPO, 1992, p. 59)

The tremendous success of UAV systems in Operation Desert Storm sends a strong message regarding the utility of UAV systems in combat. In an era of budget constraints, doing more with less is mandatory. UAVs have the capability to perform multiple functions and significantly enhance battle management systems, and are excellent force multipliers due to their combat utility and versatility. These Desert Storm lessons learned are being applied to their respective UAV systems. The lessons have helped to reaffirm the course and direction that have been taken with the SR, CR, MR, and VTOL UAV programs. (UAVJPO, 1992, pp. 61-62)

The success of the unmanned aerial vehicles (UAVs) is self-evident. Compared to manned systems, UAVs are relatively inexpensive. They can be flown in areas that manned aircraft should avoid. They eliminate the problem of downed air crews becoming prisoners of war. If required, they can be sent on one-way missions. In practice, the UAVs are best employed as complements to other manned systems, a combination that allows UAV strengths to be exploited with a human's uniquely unprogrammable intelligence, flexibility, and decision-making abilities. (Dickerson, 1992, p. 99) The combat success of the UAV concept is a reality. In each of our modern conflicts, UAVs have played an important, if often short fused, role.

IV. THE PIONEER REMOTELY PILOTED VEHICLE

In order to familiarize the reader with the operation of a combat tested UAV, an overview of the Pioneer Remotely Piloted Vehicle (RPV) is provided in this chapter. The Pioneer system provides near-real-time reconnaissance, surveillance, target acquisition (RSTA), battle damage assessment (BDA), and battlefield management within line-of-sight of a ground control station, both day and night. The Pioneer has a low radar cross-section and a small infrared (IR) signature, thereby minimizing its detectability. Figure 3 shows a picture of the air vehicle.

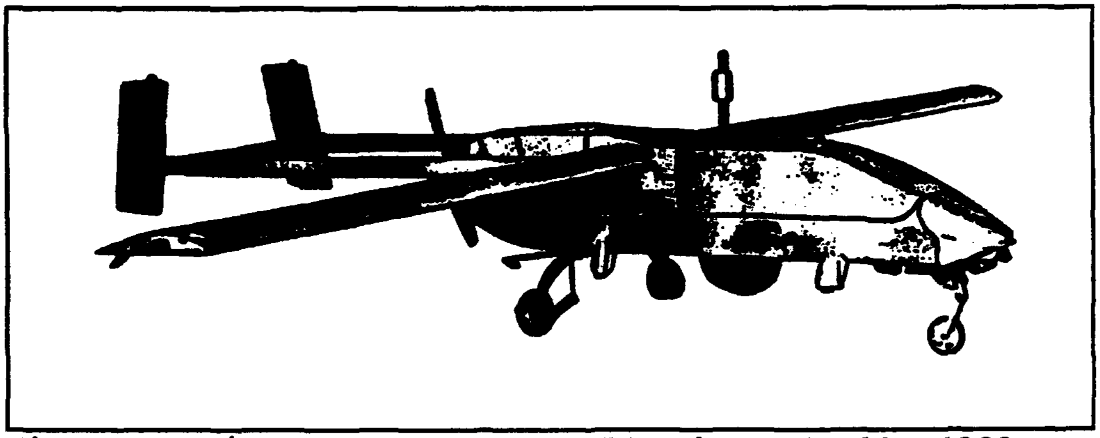


Figure 3. Pioneer RPV (U.S.N. TM Pub no 01-10, 1988, p. 2-1)

A. HISTORY

This section details the history of the acquisition of Pioneer, some of its employment and its current status. The DoD acquisition of Pioneer was based on a fundamental concept of the Packard Commission's recommendations for a system acquisition which significantly reduces the full scale development to operational deployment time cycle. The technique adopted was very simple. In late 1984, using a Marine Corps Operational Requirement for a Short Range RPV System, together with acquired information from industry as to what was "current off the shelf" (COTS) technology, a small quantity of systems that meet a minimum essential capacity (MEC) was competitively procured.

Each competitor, prior to the selection of a winner, was required to submit an acceptable proposal and then conduct an unfunded demonstration of the system's minimum essential capability. Upon selection of a winner, the systems were delivered to the Pacific Missile Test Center (PMTC) China Lake, California for operational and developmental testing, to the U.S. Marine Corps for operational assessment with a user, and to the U.S. Navy for operational assessment as a land based U.S. Navy asset. Normally, these activities would be accomplished in serial following a development cycle. Subsequently, after testing at various locations, the data was collected and collated to evaluate the results and validate the original operational requirement. (Garrison, 1992, p. 1)

Following operational fly-off at China Lake in late 1985, the DoD ordered additional Pioneer systems for a total of nine. Currently, only eight systems are operational. They are dispersed as follows: the U.S. Marine Corps has three systems, the Navy has two systems, the Army has one system, the Joint Training Facility at Fort Huachauca, Arizona has one system and there is one system at Point Mugu, California used for research and development (R&D). A picture of a Pioneer system is shown below in Figure 4.

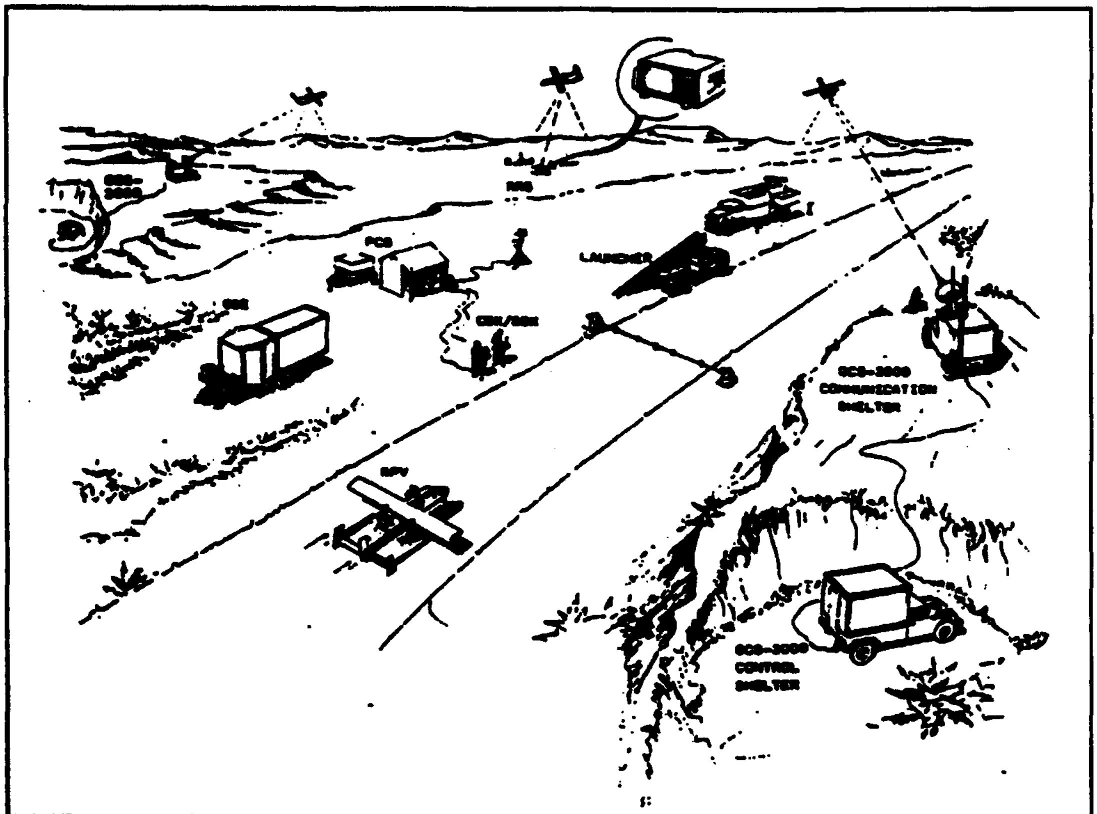


Figure 4. Pioneer System (U.S.N. TM Pub No 01-10, 1988, p. 1-2)

The Pioneer was first deployed in December 1986 aboard the U.S. Navy's battleship *U.S.S. Iowa.* Successful deployments have been accomplished by the U.S. Navy aboard battleships, by the U.S. Marine Corps aboard amphibious ships, and on land by the U.S. Army. The high point in Pioneer's operational history was its unprecedented success during Desert Shield/Desert Storm. The U.S. Army, Navy, and Marine Corps commanders lauded the UAV for its effectiveness in the areas of RSTA, naval gunfire support (NGFS), BDA, and as a battlefield management platform. By April 1992, Pioneer systems had flown about 7,000 hours in 3,300 total flights. (Garrison, 1992, p. 3)

Figure 5 pictures the first Pioneer shipboard line-assisted arrestment. The landing took place aboard the *U.S.S. New Orleans* (LPH 11) in early 1993. The Fleet Composite Squadron (VC) 6 detachment on board *U.S.S. New Orleans* also marked the first time a UAV has been launched from an *Iwo Jima*-class amphibious assault ship. (Lawson, 1993, p. 46)

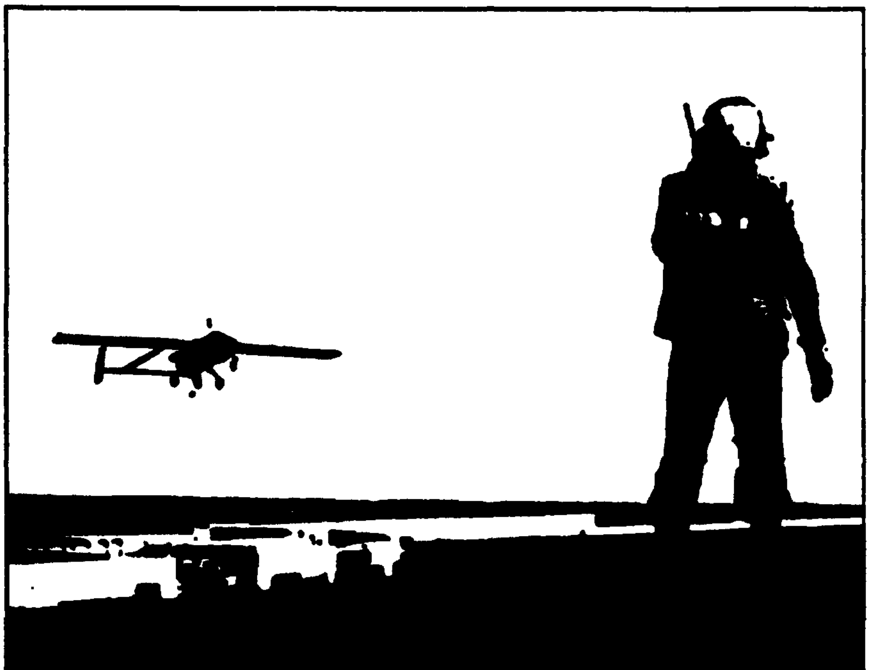


Figure 5. Pioneer approaches the *U.S.S. New Orleans (LPH 11)* (Lawson, 1993, p. 46)

B. REAL-TIME MISSIONS

A Pioneer can perform a wide variety of reconnaissance, intelligence, and special missions. Typical real-time missions carried out by the Pioneer include battlefield monitoring, artillery targeting, air strike direction, patrolling borders, restricted areas, and illegal routes, performing traffic surveys on land and at sea, fire detection, search and rescue assistance, research including weather/climate studies, and oil pipe line security and maintenance. (U.S.N. TM Pub No 01-10, 1988, p. 1-1)

During the recent Gulf War, Pioneer provided critical data to support monitoring enemy movement for the U.S. Marines, spotting weapons firings for the U.S. Navy, and conducting much needed post attack assessments for all services. As a key intelligence asset, the UAV truly came of age. Early in the naval campaign, naval gunfire from the *U.S.S. Missouri* and *U.S.S. Wisconsin* shelled and destroyed enemy positions ashore as well as Iraqi boats that had been used during raids along the Saudi Arabian coast. Pioneer RPVs were extremely effective in target selection, spotting naval gunfire, and damage assessment while the battleship's 16 inch guns destroyed enemy targets or softened defenses along the Kuwait coastline preparing for a possible amphibious landing. (Garrison, 1992, p. 4).

Navy battleships continued to fly Pioneer missions while working with allied counterparts to enforce United Nations' (UN) sanctions after the cease-fire ended ground hostilities. Pioneer systems were used to conduct reconnaissance missions along the coastline and outlying islands in support of occupying allied forces. Over Faylaka Island, the *U.S.S. Wisconsin's* Pioneer observed hundreds of Iraqi soldiers waving white flags following the battleship's pounding of their trench lines, the first ever surrender of enemy troops to an unmanned aircraft. (Garrison, 1992, p. 1)

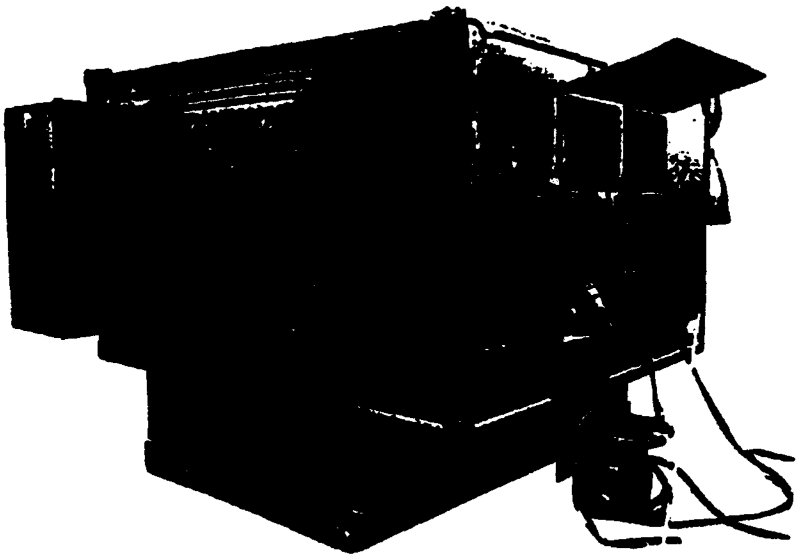
Ground forces had equal success using Pioneer as enemy positions, strengths, movements, and tactical disposition were all relayed back to battlefield commanders near-real-time, to support the ground offensive. U.S. Marines used the Pioneer to drive air strikes, provide near-real-time reconnaissance for U.S. Navy Sea Air and Land (SEAL) teams as well as force reconnaissance prior to and during special operations. (Garrison, 1992, p. 1)

C. SYSTEM DESCRIPTION

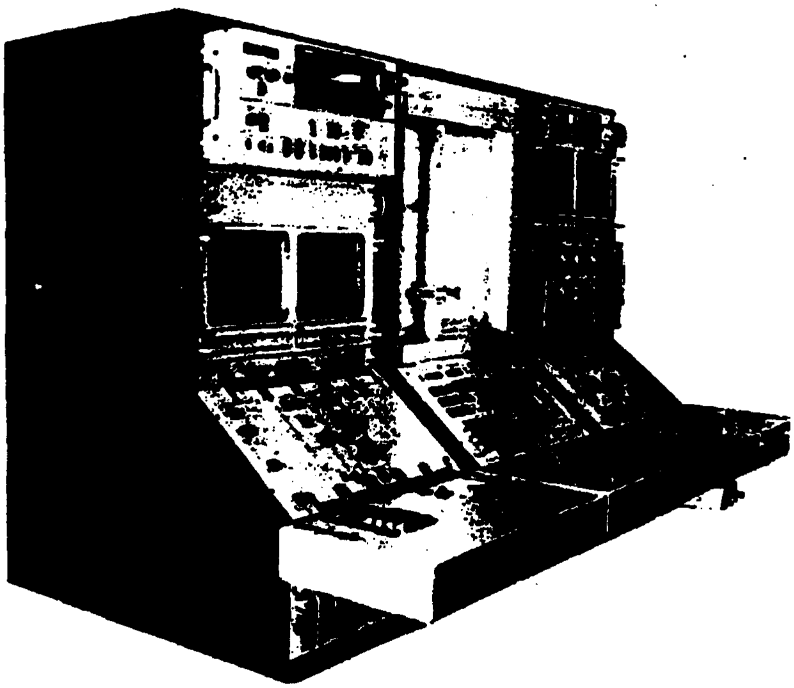
This section will detail the physical description of a Pioneer RPV, as pictured in Figure 3, and an entire system as pictured in Figure 4. The air vehicle is pusher-propeller driven, powered by a 26 HP, two stroke, twin-cylinder engine mounted in the rear, and carries 42 liters (11.1 gallons) of 100 octane low lead AVGAS. The air vehicle carries a payload designed to obtain and relay high quality video imagery. The Pioneer air vehicle is capable of operating up to five hours with daytime TV camera payload or a day/night forward looking infrared (FLIR) camera, both with near-real-time video downlink to the control station. (Garrison, 1992, p. 3) A Pioneer system consists of five to eight air vehicles, a ground control station (GCS), a tracking and communications unit a portable control station, two remote receiving stations (RRS), (only one in the U.S. Navy system), ground support equipment, an optional pneumatic launcher or rocket assisted launcher and net or runway arrestment recovery systems and various payloads. (McCune, 1993, p. 2)

The Pioneer operates between 1,000 and 13,000 feet AMSL, flies at 60 to 95 knots, and up to about 220 km from the GCS. A flight crew consists of 4 personnel and requires 16 support personnel. Line-of-sight (LOS) communications between the Pioneer and a control station must be maintained at all times for positive flight control and imagery data link. The air vehicle may be handed off from control station to control station effectively increasing the air vehicle's range to its fuel limit. This also allows launch from one site and recovery at another, i.e., ship to ship, ship to shore, or shore to shore. A GCS can control two air vehicles simultaneously (dual operations), although the video down link and positive control can be managed for only one air vehicle at a time. It can also be programmed to transit without the need to data link, further reducing emissions and detectability. (Garrison, 1992, p. 3)

The Pioneer RPV system is composed of the RPV, the GCS and other Ground Support Equipment. The Ground Control Station (GCS-2000) is composed of two truck-mounted shelters containing the control shelter and the communication shelter. The GCS-2000 controls the RPV via two uplink (UPL) channels (C-band and UHF) and one downlink (DNL) channel (C-band). The Ground Control Station (GCS) (Figure 6a) is contained in an S-250 or S-280 type shelter and includes the RPV Pilot Control Bay, Tracker Bay, and Payload Control Bay (Figure 6b). The communications shelter (Figure 7) is contained in an S-250 type shelter and includes the Communication, Tracking, and Antenna Systems and the Navigational Data System. The S-280 GCS has additional room for a mission commander, dual air conditioners, a AC/DC control panel, and an intercom system for communications between the two shelters. The use of two shelters provides protection to the Pioneer RPV system operating crew (internal pilot, payload operator, and mission commander) without detracting from the system communication range. The two shelters are mounted on trucks, thus making the station easy to transport and quick to deploy. The main function of the GCS-2000 is to control and monitor the operation of the RPV and the installed payload. However, since all preflight, takeoff, landing, post-flight, and maintenance procedures and functions can be performed from the GCS-2000, the station can be used for controlling the Pioneer RPV system during all mission steps. (U.S.N. TM Pub No 01-10, 1988, p. 1-3)



a. Outside View (GCS S-250 Shelter)



b. Inside View

Figure 6. GCS-2000 Control Shelter (U.S.N. TM Pub No 01-10, 1988, p. 3-2)

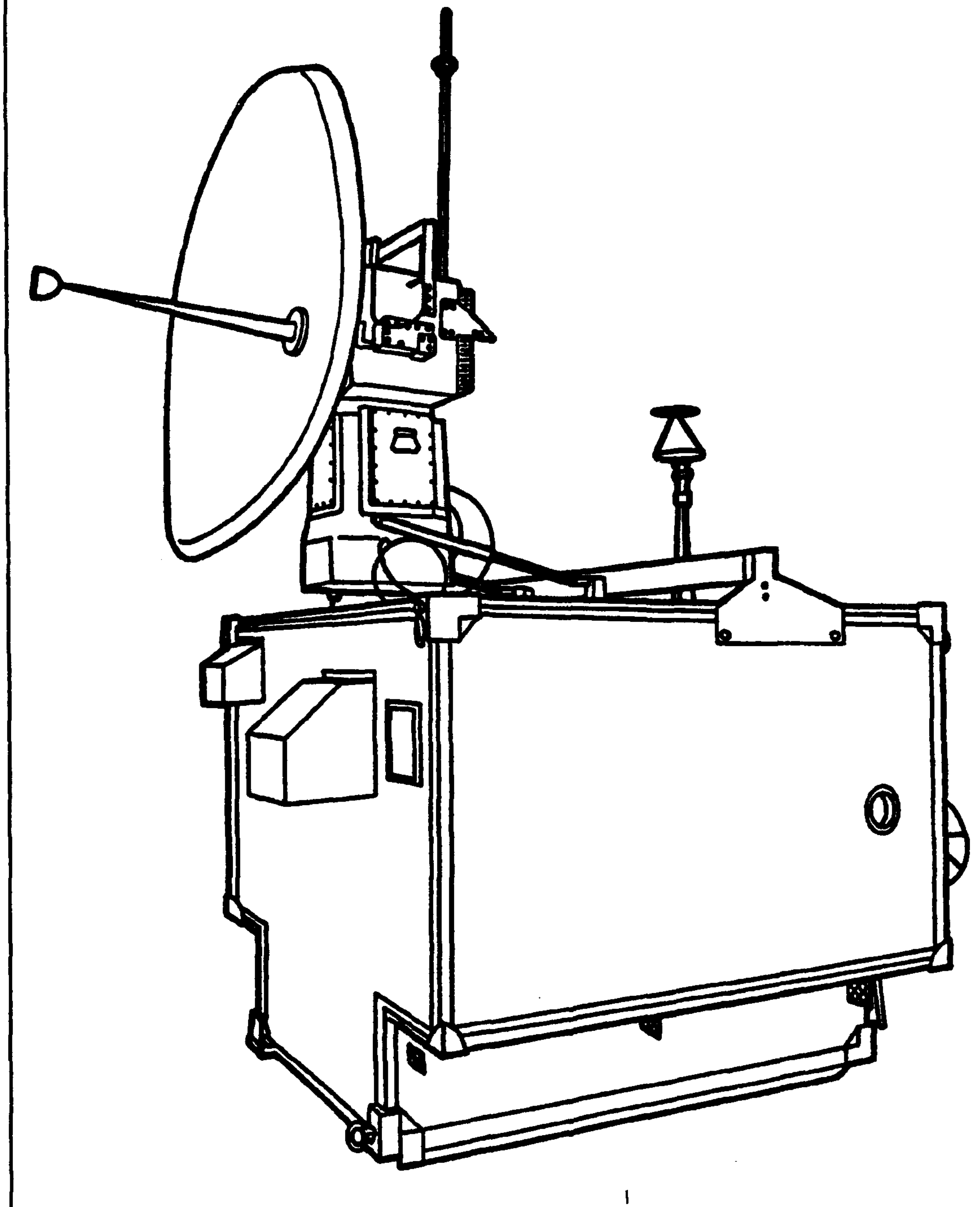


Figure 7. GCS-2000 Communications Shelter (U.S.N. TM Pub No 01-10, 1988, p. 3-9)

The Portable Control Station (PCS) pictured in Figure 8, is a small, modular portable control station for the Pioneer RPV system. The PCS is a mobile/transportable system manned by one crewmember, a pilot. Connections are provided for a copilot control box (CBX), to be used by a copilot located at the takeoff and landing site, and a student control box, to be used by a trainee. It controls the RPV mainly in takeoff and landing. Its effective control range is 25 miles (40 km) minimum. (U.S.N. TM Pub No 01-10, 1988, p. 4-1)

The Remote Receiving Station (RRS) pictured in Figure 9, is a lightweight unit that is mountable on a jeep or an armored personnel carrier. The RRS is designed to receive and display, in real time, data transmitted from the RPV. The data received by the RRS consists of a video picture recorded by a stabilized reconnaissance camera payload in the RPV. The camera, which is remotely controlled from the control stations, continuously transmits a picture of the surveyed area, which is displayed on the RRS monitor. On the basis of the received data, it is possible to make rapid decisions based on real-time information received directly from the battlefield. Reception of video from the RPV at a range of 18 miles (30 km) minimum. (U.S.N. TM Pub No 01-10, 1988, p. 5-1)

The launcher system (ZVN 401001-50) as seen in Figure 10, launches the Pioneer from an unprepared site. This is possible if the Pioneer is equipped with catapult guides and a strap catch-release mechanism. The launching system operates a pneumatic turbine that rotates a drum, around which a strap is wound. The strap, which pulls the Pioneer along the rails, is released at the end of the path when the RPV reaches the drum region. The launching system, is designed for a Pioneer with launching skids and a strap catch-

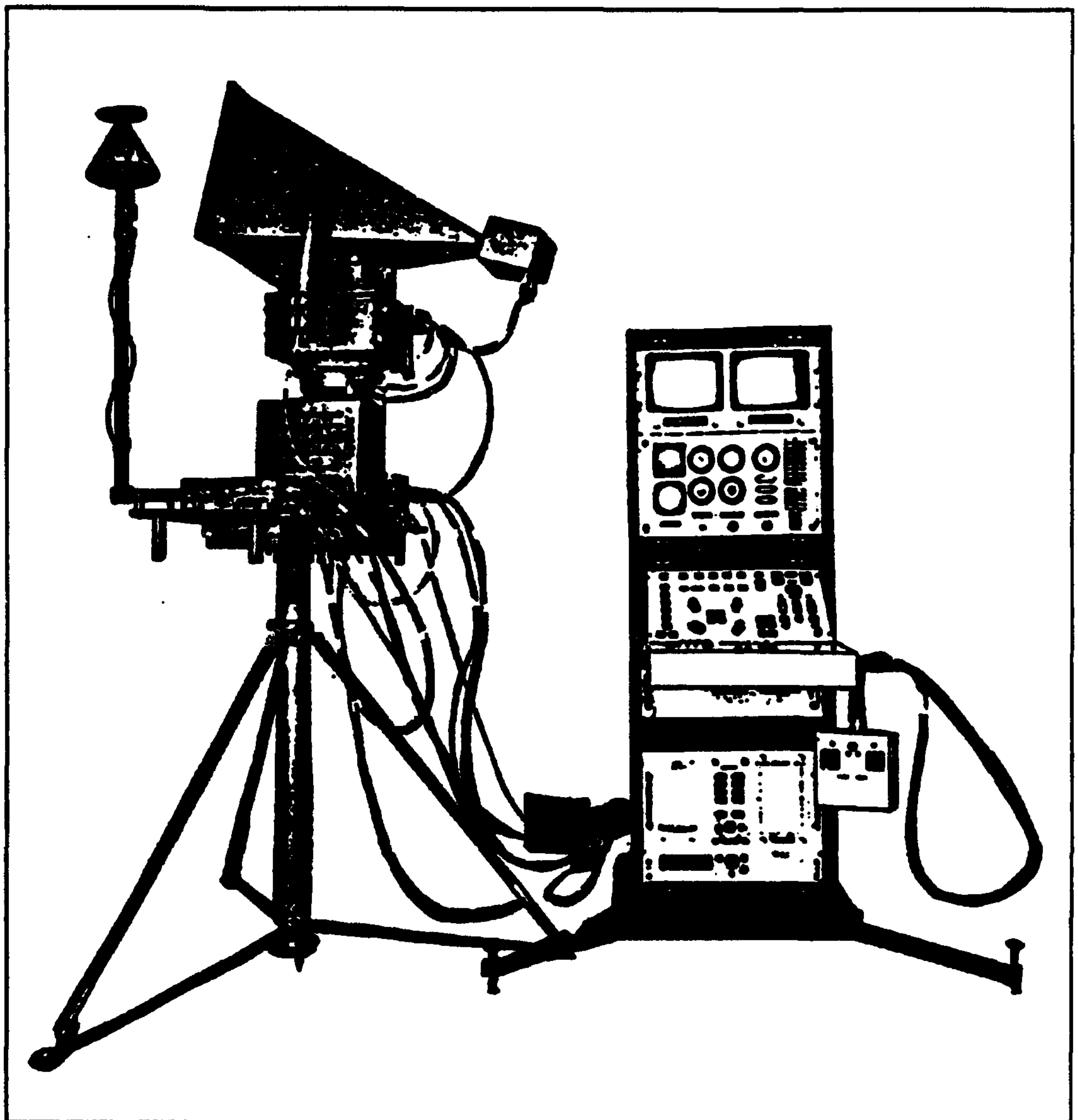


Figure 8. Portable Control Station (PCS-2000) (U.S.N. TM Pub No 01-10, 1988, p. 4-3)

release mechanism. The launching system, which is mounted on an M814 10-ton truck, consists of four principle components, a launcher, four rail extensions, a base structure, and an electrical system. (U.S.N. TM Pub No 01-10, 1988, p. 5-1)

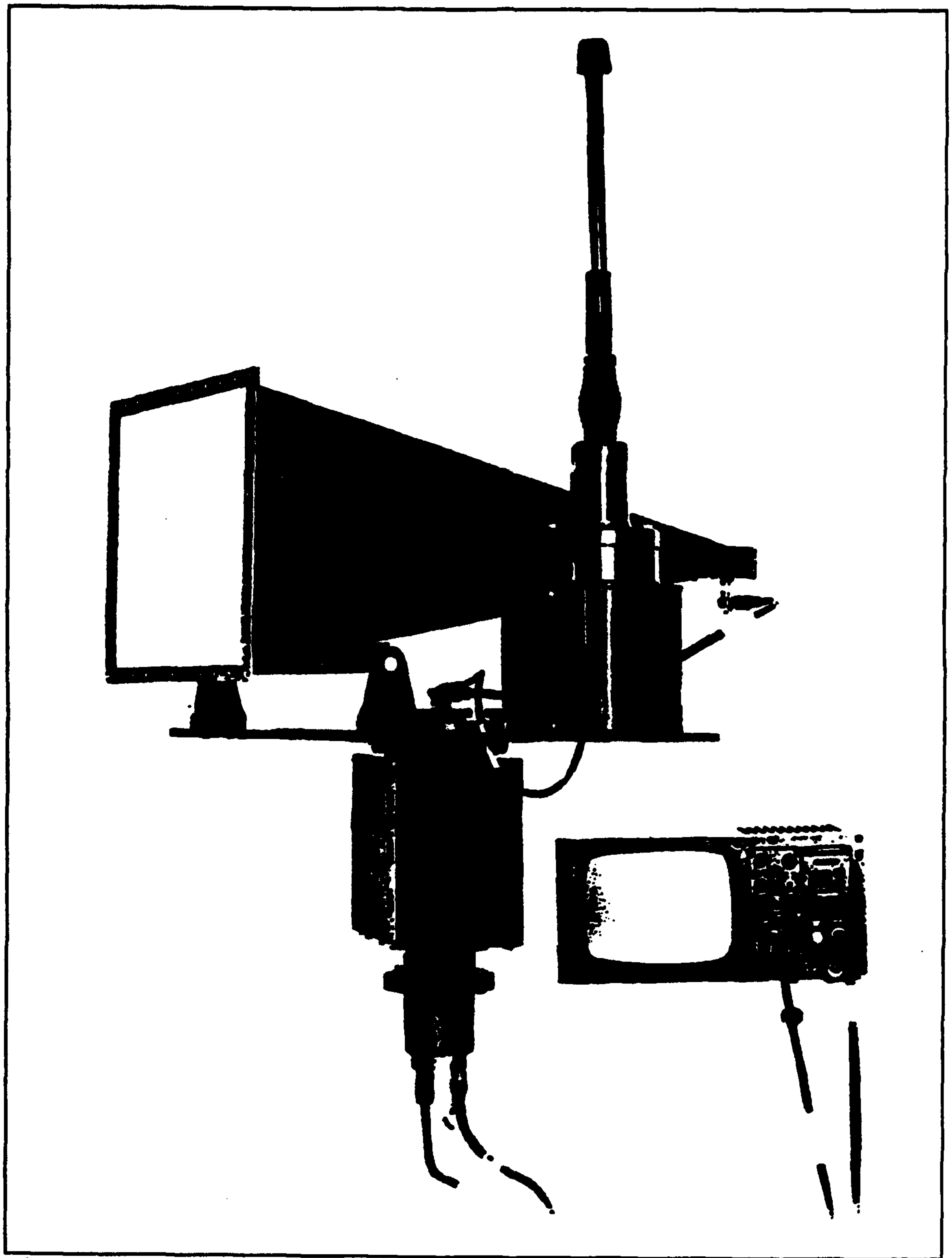


Figure 9. Remote Receiving Station (RRS)(U.S.N. TM Pub No 01-10, 1988, p. 5-2)

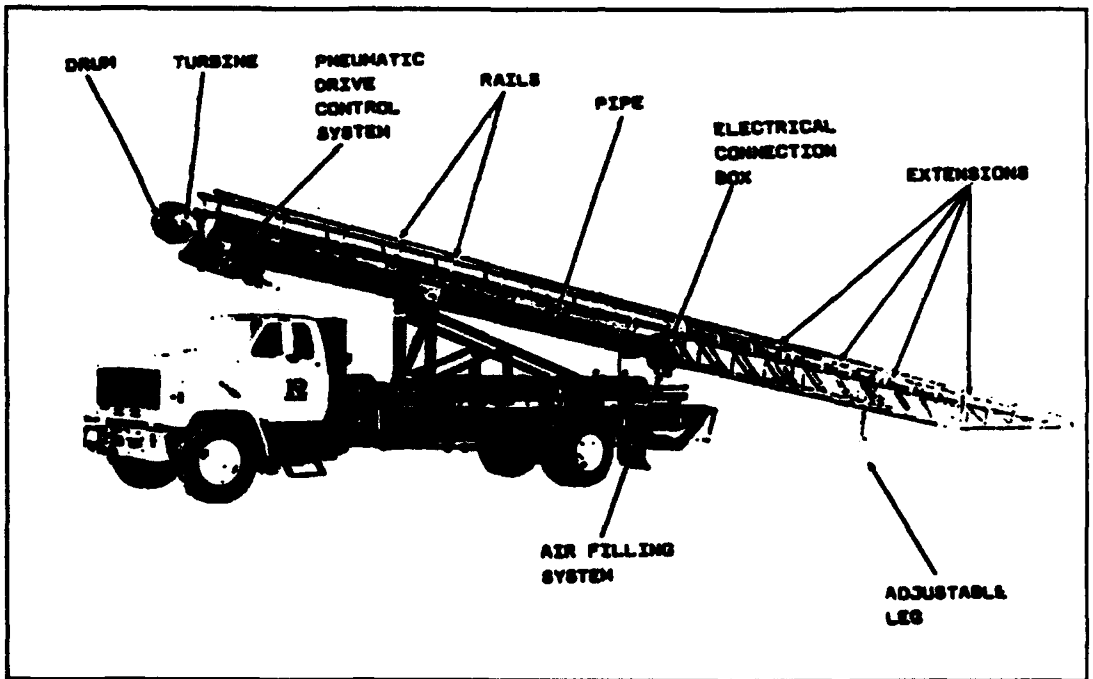


Figure 10. Launching System (U.S.N. TM Pub No 01-10, 1988, p. 6-1)

The Rocket Assisted Takeoff (RATO) launch system, as shown in Figure 11, is designed to allow the Pioneer to launch from a short runway. A disposable rocket motor is used to boost the Pioneer into the proper launch path. The launch system consists of five major components, the launch stand, the rocket motor, the rocket motor initiator, the mounting system, and the control system. After preflight procedures have been completed, the Pioneer is mounted on the launch stand. This launch stand is adjusted to the proper launch angle. The rocket motor is then attached to the mounting assembly. After the rocket motor is attached, the rocket motor initiator is installed into the rocket motor. Finally, the initiator is fired by the control system. The rocket motor then boosts the Pioneer into its proper flight trajectory. (U.S.N. TM Pub No 01-10, 1988, p. 7-1)

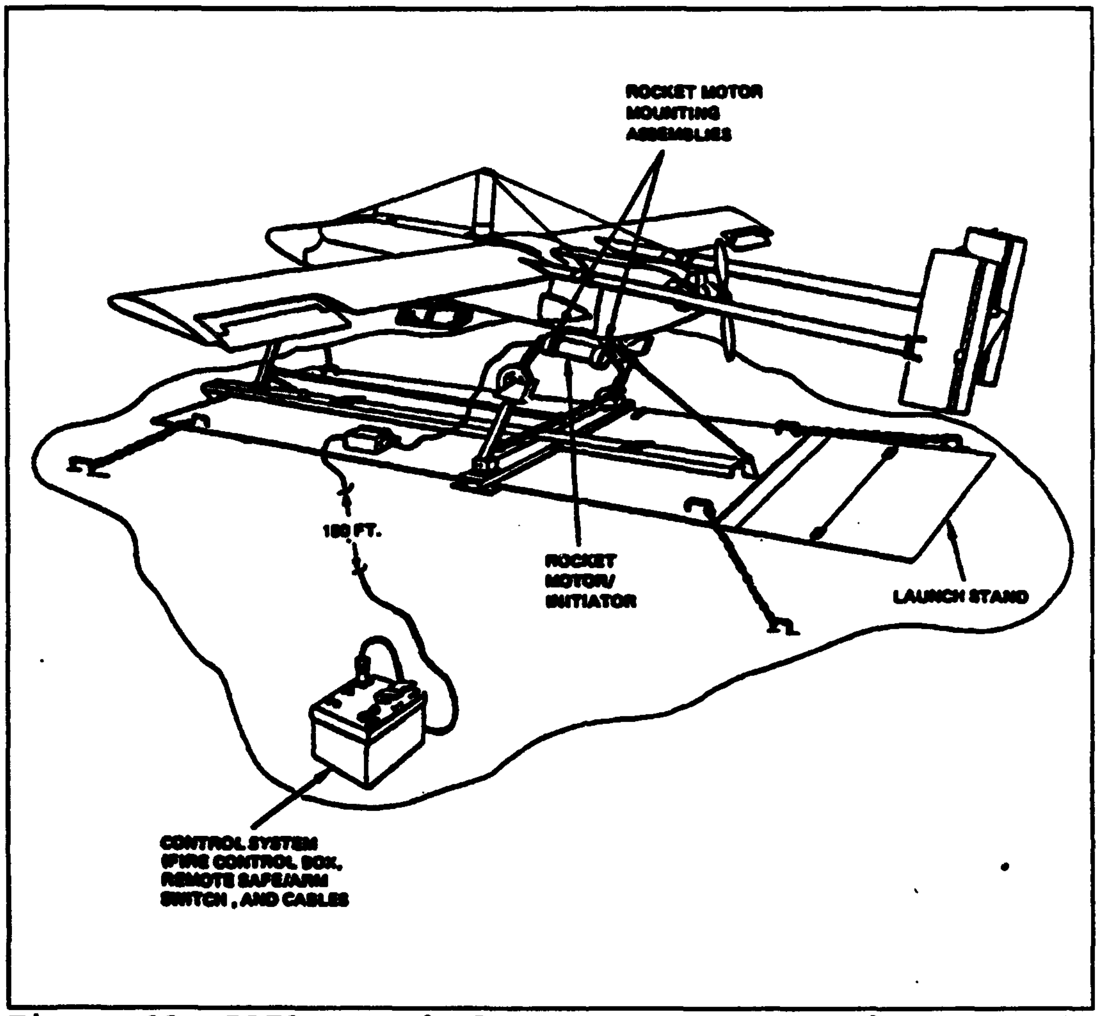


Figure 11. RATO Launch System (U.S.N. TM Pub No 01-10, 1988, p. 7-2)

Pioneer is capable of two stabilized reconnaissance payloads, the MKD-200 and the MKD-400. The MKD-200 payload is pictured in Figure 12. It is a black and white TV camera system stabilized relative to ground. It is designed to perform various tactical missions requiring real-time daylight reconnaissance. The MKD-200 payload is carried by the RPV to the target area and uses the RPV communications system to receive control commands from the observer in the control station and to transmit TV pictures and telemetry information. These missions are performed in daylight conditions, from half an hour after sunrise through half an hour before sunset (U.S.N. TM Pub No 01-10, 1988, p. 8-1).

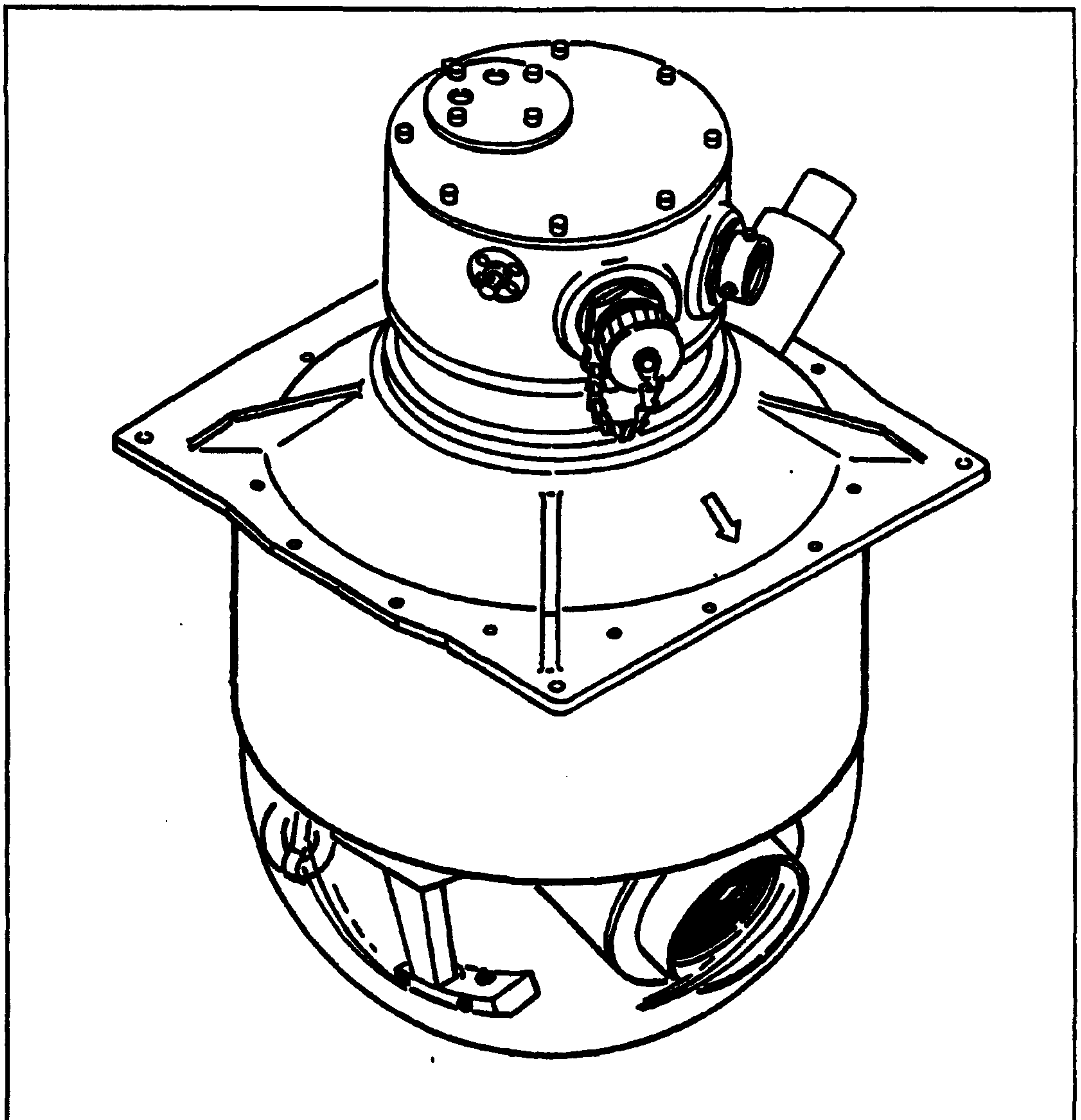


Figure 12. MKD-200 Payload (U.S.N. TM Pub No 01-10, 1988, p. 8-2)

The MKD-400 payload pictured in Figure 13 is a FLIR system that provides a video picture for reconnaissance purposes under day and night light conditions. It provides a real-time video picture from the target area, while it is remotely controlled from the control station via the communications link. The system also provides reports regarding its position in space, related to the RPV axis, allowing the control station computer to perform calculations of coordinates and artillery adjustment. (U.S.N. TM Pub No 01-10, 1988, p. 9-1)

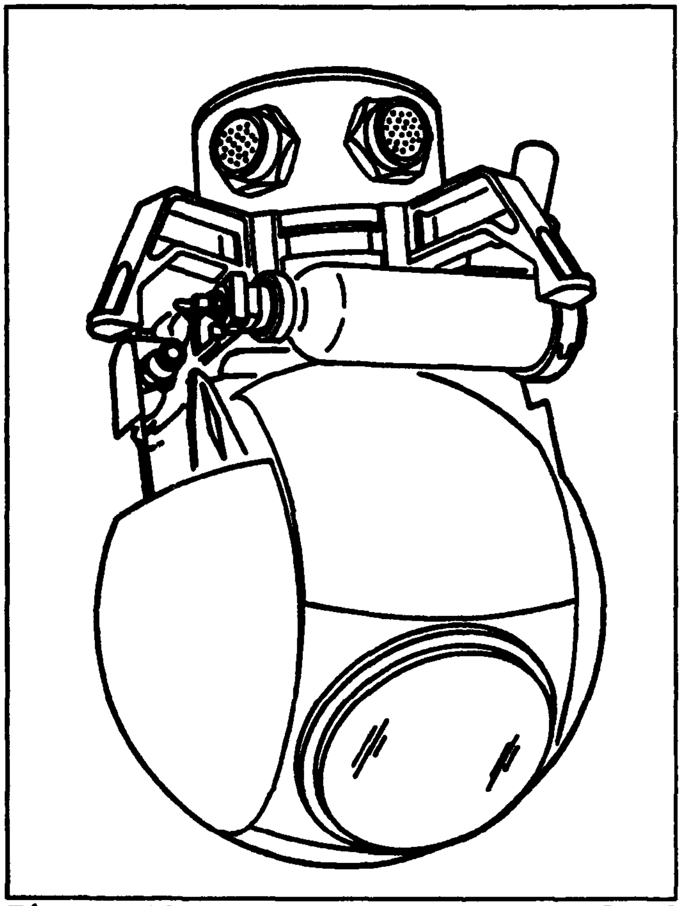


Figure 13. MKD-400 FLIR Payload (U.S.N. TM Pub No 01-10, 1988, p. 9-3)

The GSE for the Pioneer RPV system is stowed in a truck-mounted shelter and contains the essential equipment for handling, servicing, and maintaining the RPV, GCS-2000, and PCS. (U.S.N. TM Pub No 01-10, 1988, p. 1-3) The overall dimensions for the

Pioneer RPV are shown in Figure 14. The Pioneer's specifications are listed in Appendix C.

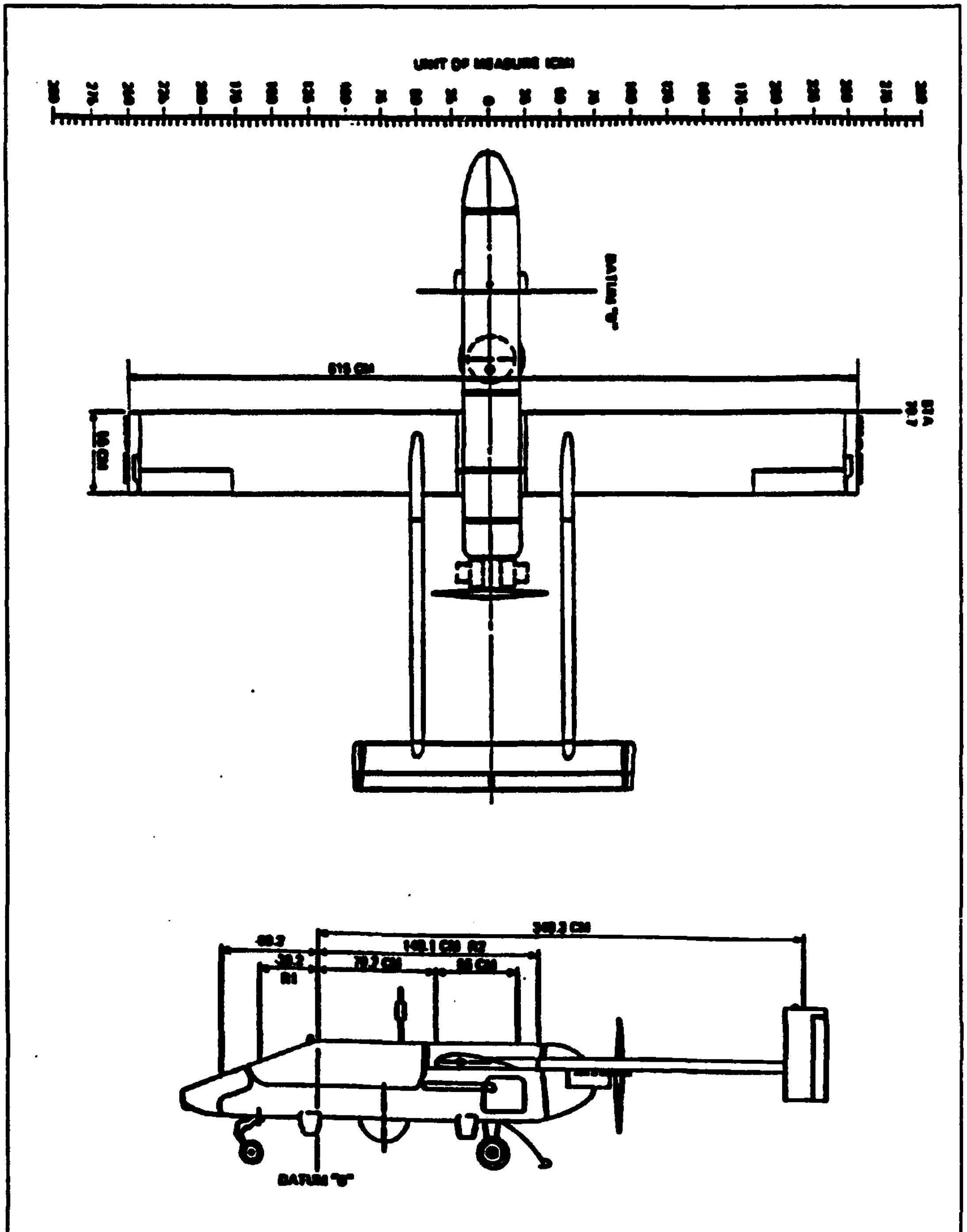


Figure 14. Pioneer RPV (Option 2 Configuration) Overall Dimensions (U.S.N. TM Pub No 02E-10, 1990, p. 1-6)

D. UPLINK / DOWNLINK

The RPVs communicate with the GCS by radio via a direct sequence spread spectrum Downlink (DNL) and Uplink (UPL). The DNL is the communications path from an RPV to the GCS. Downlink communications are in the C-band frequency range. There are two UPL channels, a primary and secondary, for communications from the GCS to an RPV. Primary channel (UPL1) communications are in the C-band frequency range. The secondary channel (UPL2) communications channel uses a frequency in the UHF range. (U.S.N. TM Pub No 02E-10,1990, p. 3-155) The Pioneer Option 2 modification allows for the simultaneous operation of up to four RPVs. Each RPV sends its subsystem status reports and video and/or telemetry (TM) data to the GCS via the downlink channel. Figure 15 details the Pioneer's communications system including the various links. (U.S.N. TM Pub No 02E-10, 1990, p. 3-157) Each RPV transmits at a different frequency, which is preset on the ground before the flight. Commands to the RPV are sent via the uplink on either UPL1 or UPL2. UPL2 is used only in the event of a primary channel failure. (U.S.N. TM Pub No 02E-10, 1990, p. 3-157)

The RPV communications system and consists of an RF head, a C-band power amplifier (PCU), a C-band diplexer (DCU), a C-band omni/directional antenna, a C-band receiver (RCU), a C-band transmitter frequency select switch, a UHF receiver (RUU), a UHF antenna, a DC-DC converter, a Video/TM transmitter (TDV) (C-band transmitter), an IFF transponder, IFF antenna and a COMM switch. One antenna is used for both the uplink and downlink C-band channels within the DCU to separate the UPL reception

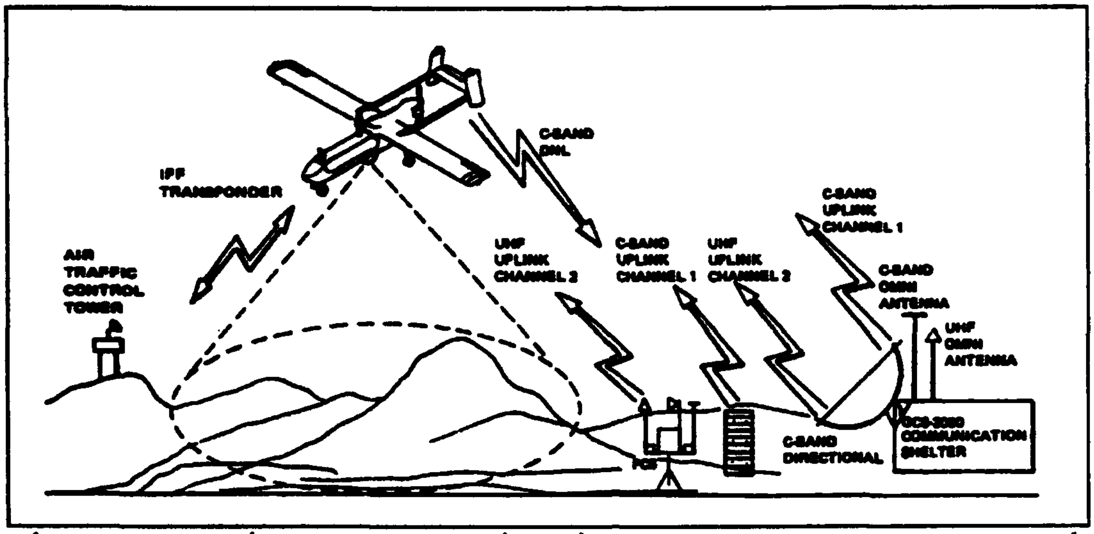


Figure 15. Pioneer Communications System (U.S.N. TM Pub No 01-10, 1988, p. 2-18)

channel from the DNL transmission channel. The DCU also isolates and protects the receivers from the high power output of the transmitter. In the RPV, the signal passes from the RF head and onto the receivers (RCU, RUU), the direct sequence spread spectrum signal is then demodulated and sent to the CPA EDU module in a Bi-Phase coded format. A transmitted signal follows a reverse scheme from the CPA EDU to the C-band transmitter. (U.S.N. TM Pub No 02E-10, 1990, p. 3-157)

The video and telemetry data, as well as the RPV status reports are transmitted on the DNL channel. The RPV-to-GCS range is calculated by timing the delay between the transmitted and received signals from the GCS to the RPV and using the speed of light. The range calculation circuits are located in the GCS-2000 Communications Shelter or PCS Communications Case. The location of the Pioneer communications package is illustrated in Figure 16. (U.S.N. TM Pub No 02E-10, 1990, p. 3-157)

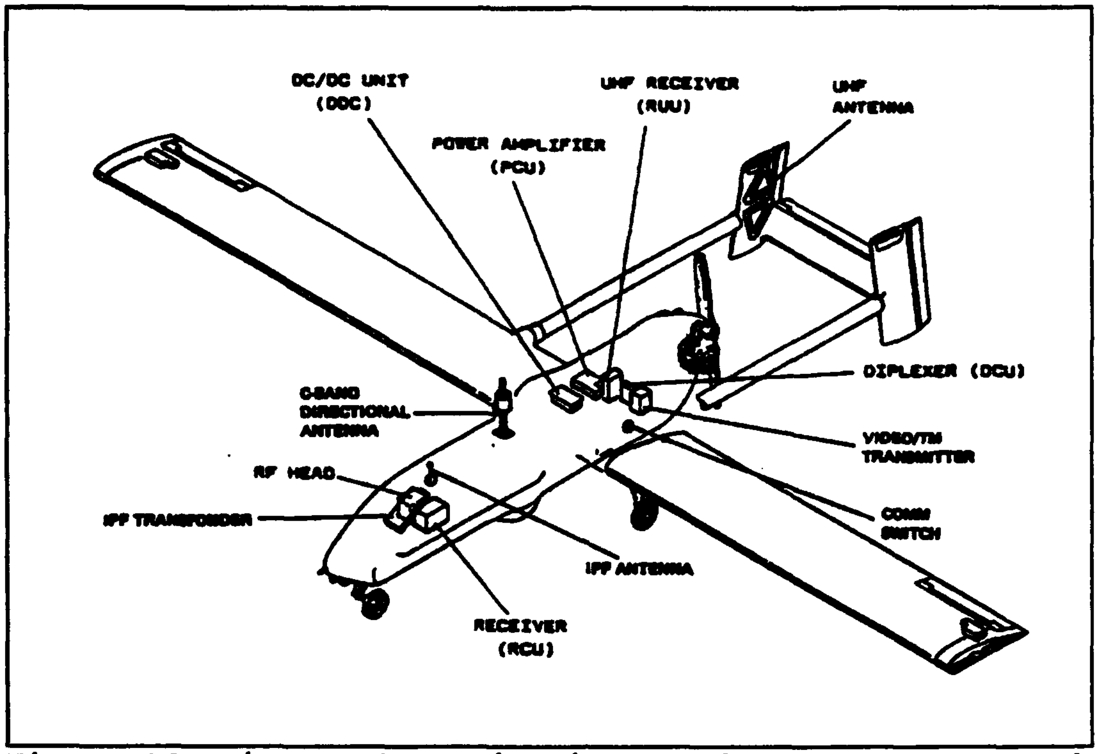


Figure 16. Pioneer Communications Package (U.S.N. TM Pub No 01-10, 1988, p. 2-19)

E. NAVIGATION AND CONTROL

The Pioneer's electronic control system centers around the Central Processing Assembly (CPA) and includes the sensors and servos used in flight control. The CPA supervises the control and communications of the RPV. The CPA decodes command signals received from the GCS on either of the two uplink channels at one of the RPV receivers, RCU (C-band receiver) or RUU (UHF receiver). (U.S.N. TM Pub No 02E-10, 1990, p. 3-52) The CPA also encodes the RPV status reports and data (telemetry) signals for transmission to the GCS on the downlink channel from the RPV C-band transmitter. The CPA contains logic that controls and coordinates the RPV flight mode selection. The CPA consists of seven modules which include the Encoder/Decoder Unit (EDU), Autopilot module (APE), Navigation module (NVC), Return Home and Memory Module (RH), Logic module, Auxiliary module (AUX), and the Buffer module. Especially important to the RPV's navigation, are the first four modules i.e., EDU, APE, NVC and RH. (U.S.N. TM Pub No 02E-10, 1990, p. 3-53)

All communications to and from the CPA pass through the EDU module via the Decoder and Encoder. Commands received on uplink channel or reports/data transmitted on downlink channel are sent in pulse code modulation (PCM) using the Bi-Phase Space protocol. The RPV flight control system (FCS) pictured in Figure 17, is controlled by the Autopilot module. The autopilot controls the RPV by inputting flight parameters measured by the sensors into control loop circuits. The signals are summed (compared) with the input command signals and the resulting error (difference) signal is used to actuate the flight surfaces and throttle servos. (U.S.N. TM Pub No 02E-10, 1990, p. 3-157)

The autopilot enables control of the RPV by interpreting sensor input data and transferring commands to the flight controls. Figure 18 shows the five main sensor units of the flight control system. They are the vertical gyro, the yaw rate gyro, the altimeter, the airspeed indicator and the flux valve (compass). All of the sensors are connected to the CPA which permits the autopilot to perform its functions. All uplink commands and downlink report signals serve as the outputs and inputs respectively from and to the GCS via the encoder/decoder unit (EDC) module in the pilot bay of the GCS.

The first of two autopilot cards contains circuits for the Direction/Roll (Ailerons), the Yaws Rate (Rudders) Loop, the Autopilot Critical Failure Control circuit, and the regulators for the gyro and sensor supplies. The second autopilot card contains circuits

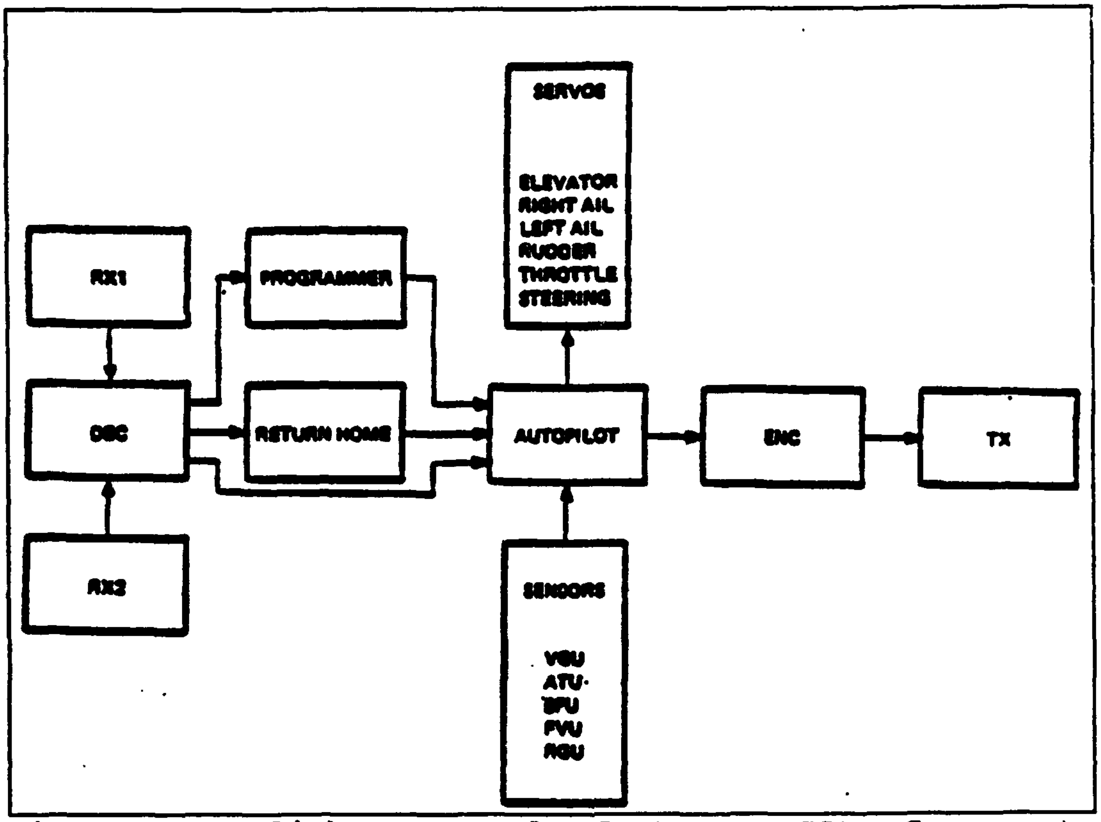


Figure 17. Flight Control System (FCS) Components (U.S.N. TM Pub No 02E-10, 1990, p. 3-94)

for the Altitude and Speed Control (throttle and elevators) Loops, Fuel Sensor Circuit and Servo test points. The Compass card includes circuits used to calibrate the flux valve inclination vector angle (tan λ, cos ϕ, and sin ϕ; this calibration is essential for the RPV to maintain its correct heading relative to north after banking or rolling). It also processes and filters all of the analog input stick mode command signals, which input the APE control loops (Aileron, Elevator, Rudder, and Throttle). In addition, the compass card filters the bypass signals to the relevant servos and contains the 9-bit altitude logic circuit. (U.S.N. TM Pub No 02E-10, 1990, p. 3-53)

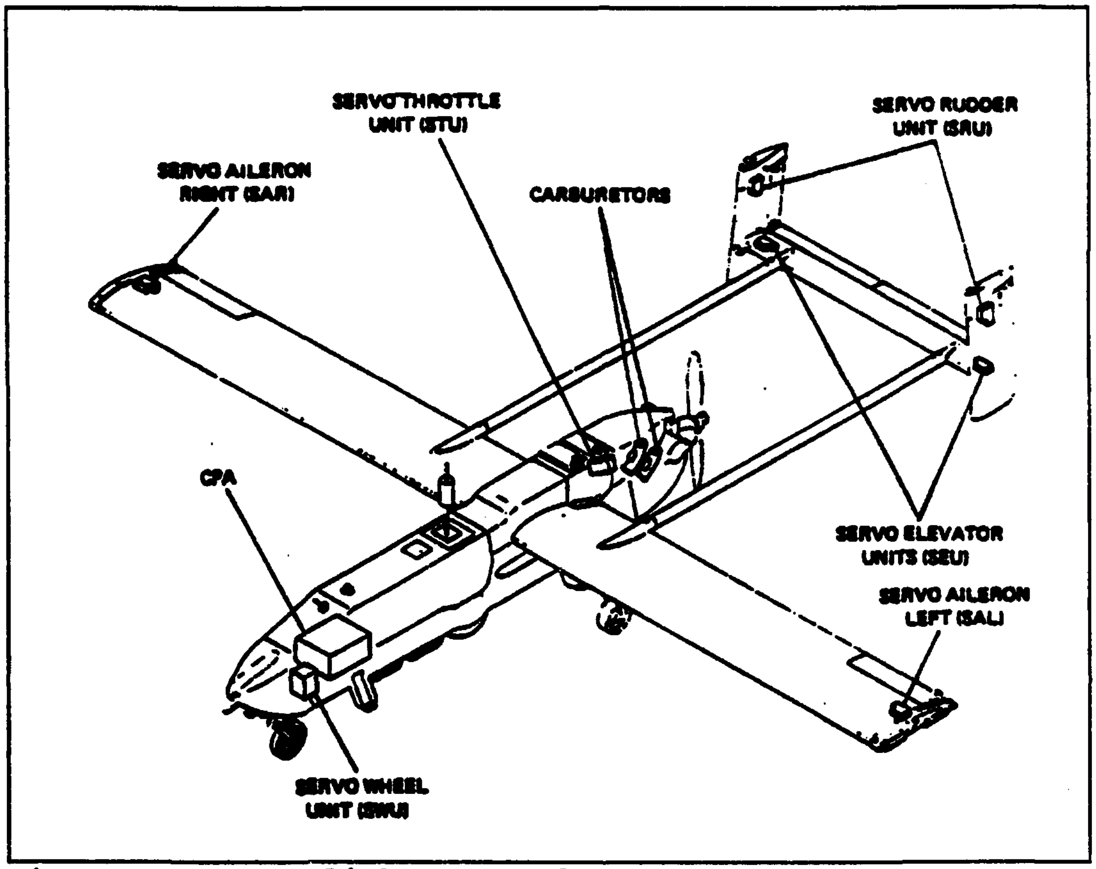


Figure 18. RPV Flight Control System, Servos (U.S.N. TM Pub No 02E-10, 1990, p. 3-84)

The NVC module uses a GPS onboard the RPV to obtain positional fixes. The NVC is a microprocessor-based design which is programmable by the pilot to fly to specific way points. The NVC module allows the RPV to be flown in a programmed flight mode using way points defined by the human internal pilot located in the GCS. In this mode, the RPV functions autonomously, flying with or without RF communications. The NVC is interfaced to a GPS within the air vehicle as well as other circuit card assemblies within the CPA. When operating in the programmed flight mode, a program is downloaded to the RPV from the control station. This program basically defines a series of way points to which the RPV is to fly. The NVC checks the current program step to see where it is ordered to fly. It also checks the GPS to determine the RPV's current position. The NVC then calculates how to fly from the current position to the ordered way point and provides instruction to the Autopilot module to perform the actual flight. This process is continued along the flight to the way point to provide accurate way point navigation. After the way point is reached, the NVC increments to the next program step and the process repeats. The program may be composed of up to 96 steps. Each step may define the following information:

1. The coordinates (way points) in the UTM format to which the RPV is to fly.
2. The holding time the RPV is to spend circling the way point.
3. The attitude and airspeed the RPV is to maintain.
4. RPV system commands for the transmitter, beacon, IFF, and payload systems.
5. Continue to the next active program step or end programmed flight mode.

The program is loaded/updated using the Navigation Program Loader (NPL) push button on the pilot's control table. The program steps can also be monitored and modified by the pilot during flight. Information pertinent to the navigation flight is provided in the downlink for display to the pilot. This information includes present location of the RPV, current program step (way point), status of NVC and GPS operation, and operating mode of RPV systems. (U.S.N. TM Pub No 02E-10, 1990, p. 3-128)

The NVC module enables the Pioneer to fly independently without the needing to communicate with the GCS when radio silence is necessary. Report transmission and/or command reception can be stopped when required. Report Inhibit (downlink transmission silence) is used when the RPV is flying over enemy territory and there is a need for radio silence. Downlink radio silence is achieved by switching off the RPV transmitter. Data Inhibit can be requested in one of the program steps whenever radio silence is required. The RH module includes a memory into which flight parameters are loaded before or during flight, digital to analog converters, and various counters and clocks used to time the RPV return flight legs.

The NVC card is a microprocessor-based circuit card assembly. There are three interfaces to the NVC in the system. An RS-422 serial interface is used as the communications link between the NVC and the GPS. RPV sensors are interfaced using a digital peripheral interface. Analog signals provided by some sensors are converted to digital form to allow the microprocessor to read them. The NVC also converts digital data to analog form for output to some modules. Command control information is transferred between the NVC and the GCS through a digital interface via the EDU.

The microprocessor contains the logic and support circuitry required to perform programmed operations. A math coprocessor is used to speed up the mathematic computations performed by the NVC. The microprocessor and the math coprocessor share a common timed multiplexed address/data bus. This bus is demultiplexed to provide separate address and data bus paths to the rest of the card. A bus controller interprets the status and control signals of the processors to generate the bus control signals (read, write, and timing) that define and control the bus operations. Individual logic elements on the NVC card are identified in a memory mapped configuration. An address decoder interprets the information on the address bus to identify which logic elements the microprocessor is accessing. The resulting device select signals enable the logic element specified to respond to the bus access. System memory for the NVC card consists of EPROM/EEPROM (for non-volatile data storage) and RAM (for temporary or workspace data storage). The EPROM/EEPROM mainly provides the operating system and control program storage for the microprocessor, while the RAM is used to store the downloaded programmed flight instructions. A programmable interval timer (PIT) provides timing references required by logic on the NVC card. A programmable interrupt controller (PIC) is used to monitor certain status signals on the NVC card for notification to the microprocessor.

The Pioneer uses an onboard GPS to calculate its current position. The microprocessor on the NVC card conducts data transfer with the GPS to send commands and instructions to the GPS as well as to receive position and status information from the GPS. These transfers are conducted over an RS-422 serial interface via a universal synchronous/asynchronous receiver/transmitter (U.S.ART). When the microprocessor sends data to the GPS, the U.S.ART then formats the data for RS-422 serial transfer to the GPS. The U.S.ART issues an interrupt to signal the PIC when it is ready for another data transfer. When data is received from the GPS, the U.S.ART converts the data from serial format to parallel and issues an interrupt to the PIC to inform the microprocessor that data is ready. The microprocessor then addresses the U.S.ART and reads the data over the internal bus.

The Pioneer has two normal and two emergency modes of flight as shown in Figure 19. In the normal UPL mode, the UPL stick control is used for regular stick control during takeoff, landing or in the event of an autopilot outer loop failure. The UPL stick control is used in the event of a critical autopilot failure. In this mode the servos are directly activated from the GCS. The UPL Knob Control is used to set the altitude, airspeed, and heading/roll of the RPV via knobs in the pilot bay at the GCS. The navigation control mode is used when the RPV flies according to the 16-step program.

The RH Delay mode is used in the event of a loss of both uplinks. Figure 20 shows how the RPV flies for 32 seconds according to the last flight commands sent from the GCS. The RPV then reverts to the RH mode. The RH mode directs the RPV to climb in altitude and attempt to reacquire the uplink. Prior to launch, the RPV can be programmed climb with or without a spiral. If the RPV fails to reacquire the link, the RH module outputs flight parameters to guide the RPV on a return home flight path. The RPV will fly up to 159 minutes on the return home flight path then spiral down until either:

1. The RPV reacquires the uplink.
2. The engine is cutoff.
3. The fuel is exhausted.
4. The RPV reaches ground cruise altitude.

The Glide mode is used in the event of a loss of both uplinks for 2 seconds while the RPV is being launched or recovered i.e., over the runway. (U.S.N. TM Pub No 02E-10, 1990, p. 3-53)

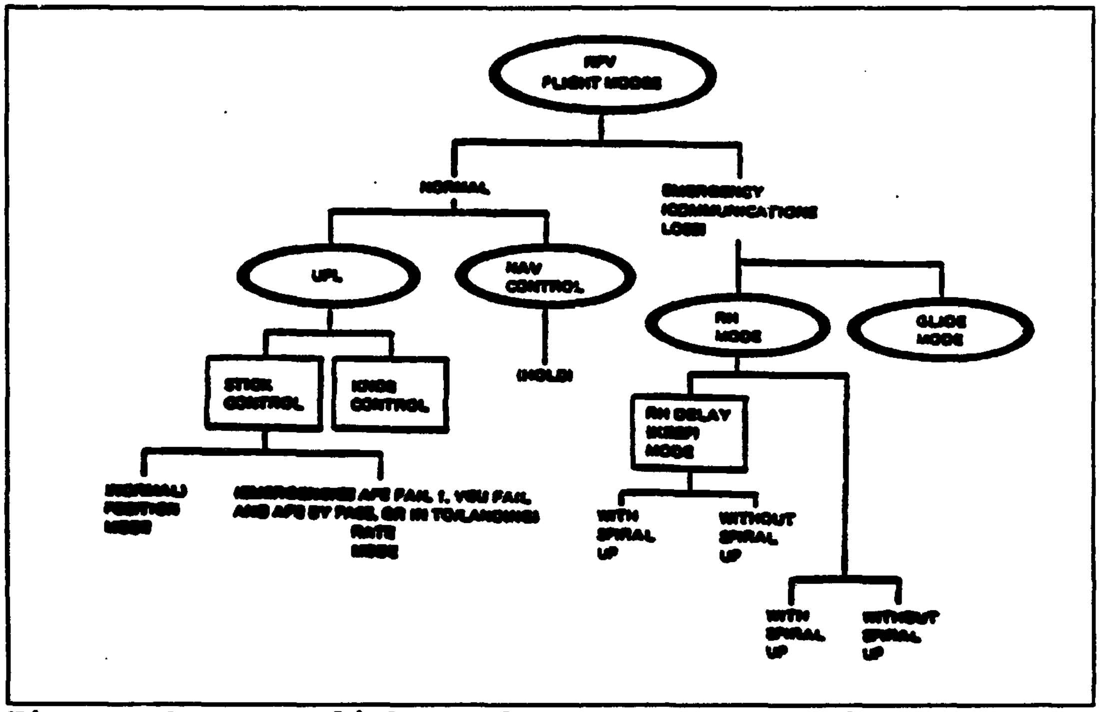


Figure 19. RPV Flight Modes (U.S.N. TM Pub No 02E-10, 1990, p. 3-2)

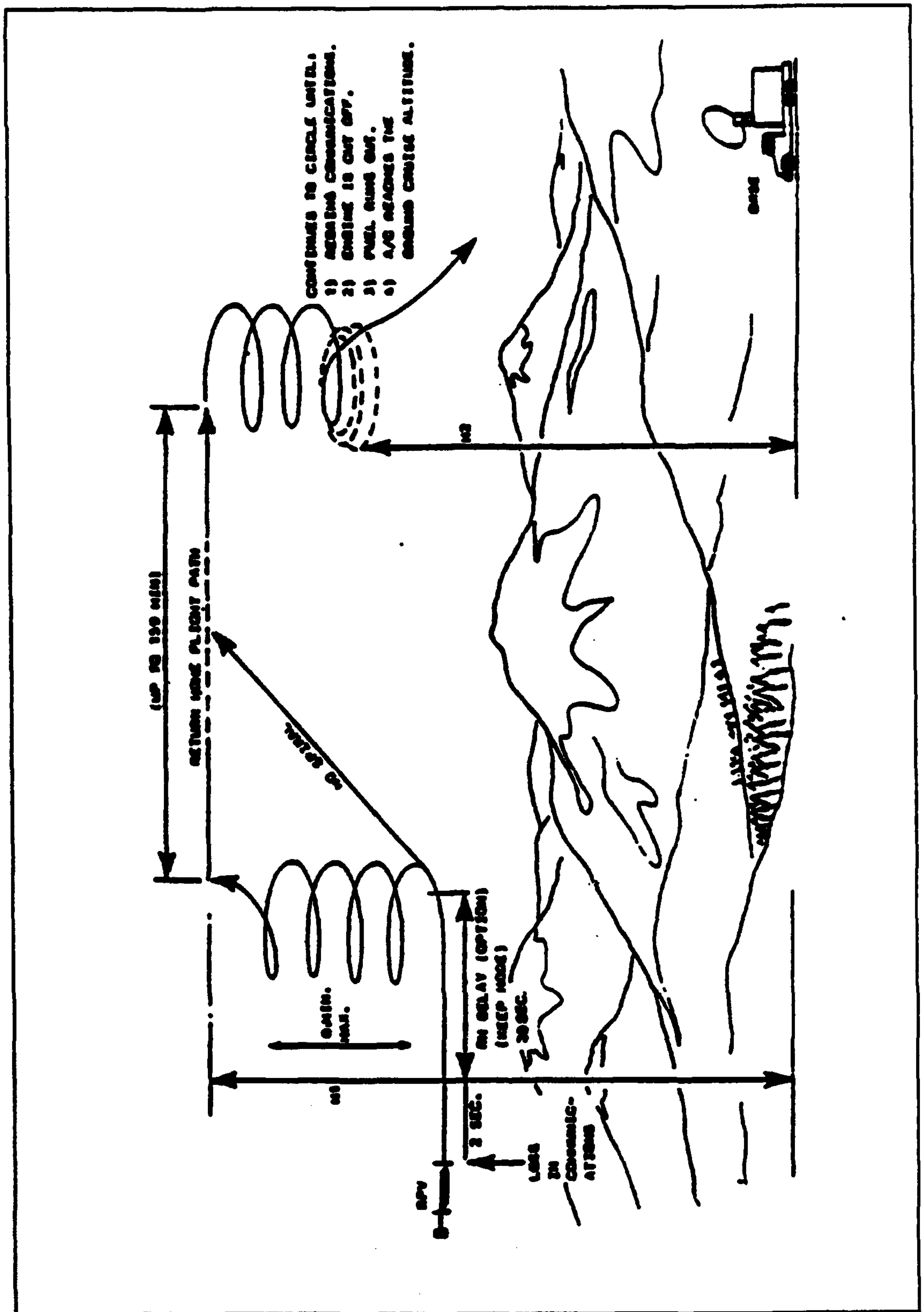


Figure 20. Return Home (RH) Navigation (U.S.N. TM Pub No 02E-10, 1990, p. 3-133)

F. AIRFRAME

The RPV airframe is divided into six parts including the fuselage, landing gear and arresting hook, wings, tail and boom assembly fuel system, and powerplant. (U.S.N. TM Pub No 02E-10, p. 3-5) Side and overhead views of the RPV airframe are shown in Figure 21. A description of each of the airframe components appears in the paragraphs that follow.

1. Fuselage

The electronic and navigation units, power unit and servos, etc, are housed in various compartments in the fuselage. The payload is housed in the RPV's mid section and is covered with a transparent canopy. The fuselage is of fiberglass construction with four bulkheads located at stations 390, 741, 1142 and 1553. The fuselage skin is made of fiberglass, except for the main access panel, which is made of a composite material (honeycomb/fiberglass), and the nose panel which is made of KYDEX. The propulsion unit is mounted on the rear fuselage bulkhead (at station 1553) and drives a pusher-type propeller. There are two hinged engine cowlings with quick-release fasteners. These are perforated and coated with fiberglass. The fuselage is divided into the forward, mid, and rear sections. The fuselage measures 12.53 feet (3.82 m) in length and 3.41 feet (1.04 m) in height. (U.S.N. TM Pub No 02E-10, 1990, p. 3-5)

2. Landing Gear and Arresting Hook

The landing gear consists of a nonretractable tricycle gear with a steerable nosewheel and an arresting hook. When the RPV lands on a runway or flight deck, a

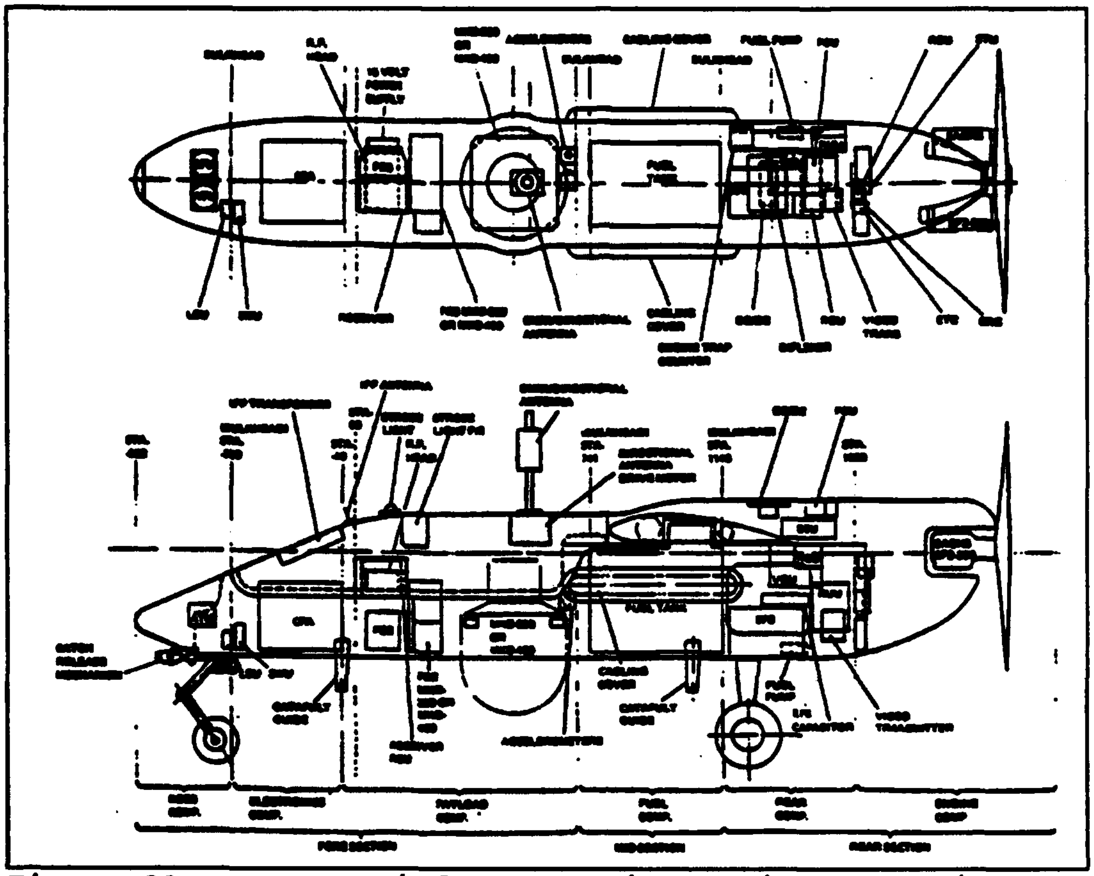


Figure 21. RPV Airframe Main Units (Option 2 Configuration) (U.S.N. TM Pub No 02E-10, 1990, p. 3-7)

rear-pointing hook helps bring the RPV to a halt after touchdown. The arresting hook is spring-loaded and has a specially designed shape to insure a reliable capture of the arrester cord. Small deck shipboard recoveries use a large vertical net to catch the Pioneer. (U.S.N. TM Pub No 02E-10, 1990, pp. 3-6, 3-7)

3. Wings

Each wing has two parts, a right and a left half, which are attached to the upper side of the fuselage with four clevis pins passing through four lugs on the wings' underside. The overall wing span is 16.89 feet (5.15 meters). The wings are made of Kevlar ribs, filled with foam (for flotation in the event of a water landing), and covered with doped fabric. Two aluminum tubes with clevis assemblies on the ends run the length of each wing. The tubes carry all of the load acting on the wings. The wings are connected together by pins inserted in the clevis assemblies. Servo actuated ailerons are installed in the outboard section of each wing. The ailerons are designed to collapse whenever a force greater than 15 lbs. is applied perpendicular to the aileron's normal travel. This design is used to lessen the leverage that can be exerted on the servos during net landings. Access panels are located on the end ribs in each wing to allow access to the aileron actuators and on the underside of the right wing for access to the flux valve. The wing tip covers are made of fiberglass and are designed to minimize edge turbulence. The ailerons are made of balsa wood. (U.S.N. TM Pub No 02E-10, 1990, p. 3-13)

An aluminum bracket, with plug receptacles for the electrical connection from the fuselage to the wing, is located on the trailing edge of the wing. Position lights are located on the wing tips. A green light is located on the right (starboard) wing and a red light is located on the left (port) wing. Clear plexiglass strips in front of each light focus part of the light's energy forward for increased night visibility. (U.S.N. TM Pub No 02E-10, 1990, p. 3-13)

4. Tail and Boom Assembly

The wing and tail boom assemblies are installed and removed from the RPV as one unit. The booms are made of Kevlar tubing 3 inches (7.62 cm) in diameter and 79.5 inches (202 cm) long. The right and left booms are inserted into wing receptacles and are fastened to them with bolts. The tail consists of a horizontal stabilizer, twin elevators, twin vertical stabilizers, and dual rudders. (U.S.N. TM Pub No 02E-10, 1990, pp. 3-13 - 3-17)

5. Fuel System

The fuel system consists of an 11.1 gallon (42 liter) integral-sealed fuel tank, a fuel level sensor, fuel filter, fuel pump, and drain valve fuel tank check valve. The fuel is a 50:1 mixture of 100 octane low lead AVGAS and natural petroleum based high quality 2-stroke oil, BIA certified for TC-W. A fuel filling opening to the integral tank is located on the cover of the fuselage at the wing root. Typical fuel consumption based on a gross weight of 381 pounds (173 kg) is shown in Figure 22. (U.S.N. TM Pub No 02E-10, 1990, p. 3-17)

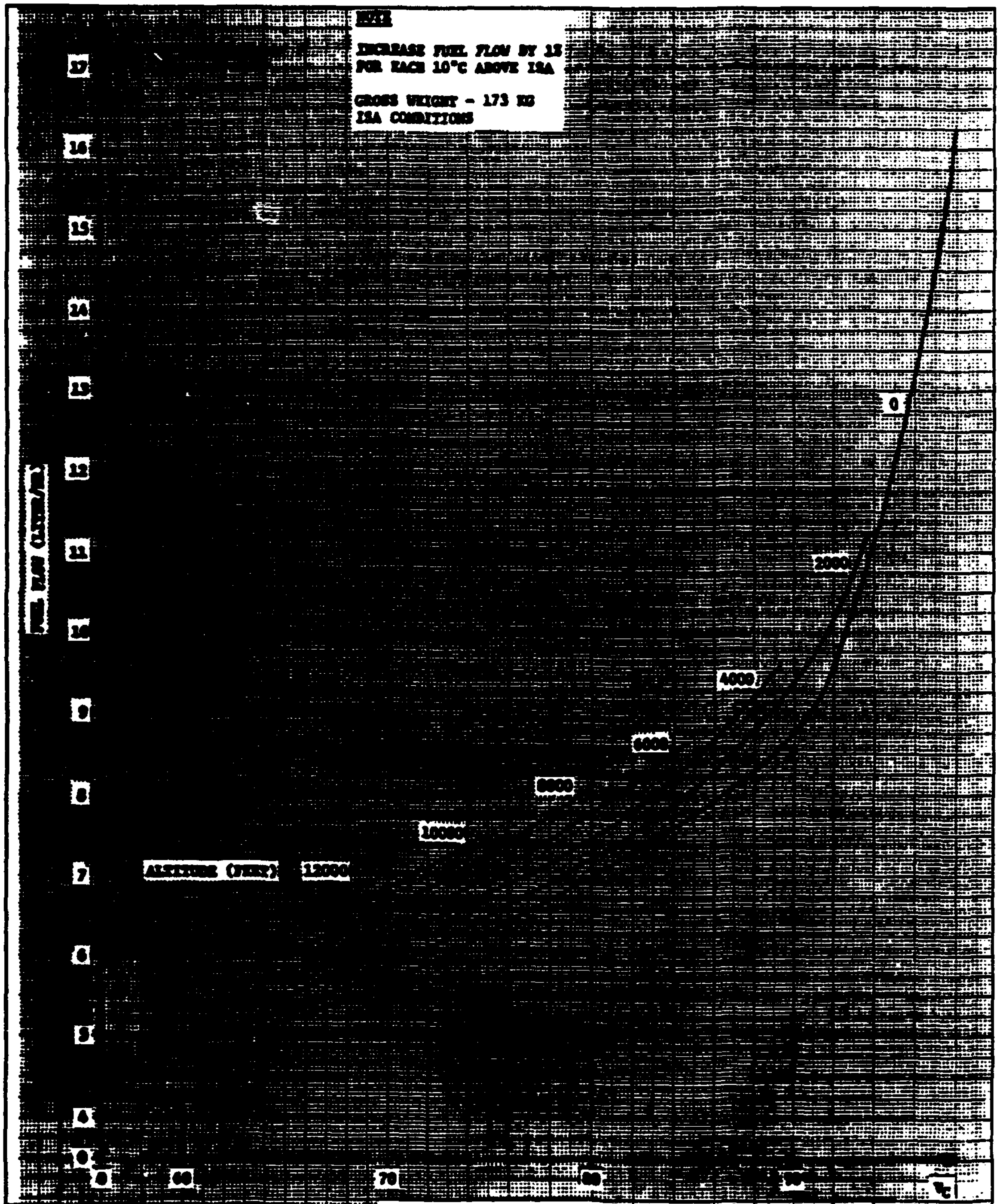


Figure 22. Fuel consumption in cruise (173 kg) (U.S.N. TM Pub No 01-10, 1988, p. B-14)

6. Powerplant

The Pioneer is powered by a horizontally opposed twin-cylinder, crankcase-scavenged, two-stroke engine pictured in Figure 23. Figure 24 shows the engine's twin carburetors mounted on the crankcase. The engine mount serves as a back cover for the crankcase and as a mount for the generator. It is supported on three dynafocal shock mounts. A generator is coupled directly to the opposite end of the crankshaft and has a Woods flexible coupling drive. This allows for quick installation and removal of the generator to correct misalignments, and for protection from shock loads through the crankshaft. (U.S.N. TM Pub No 02E-10, 1990, pp. 3-23,24) The RPV engine has a magneto ignition system that senses a triggering signal from a magnet, which is an integral part of the flywheel. The engine starter is a part of the RPV ground support equipment. The starter, mounted on a carrying cart, has a shaft that is inserted into the starting lug of the propeller hub when the engine startup is required. Figure 25 shows the two blade 29" diameter, 18" pitch propeller manufactured by the Sensenich Corporation. It is designed to operate at a 60-knot climb, developing 20 kW (26.82 HP) at 7,000 rpm. It is a pusher-propeller with clockwise rotation when viewed from the rear. (U.S.N. TM Pub No 02E-10, 1990, p. 3-28)

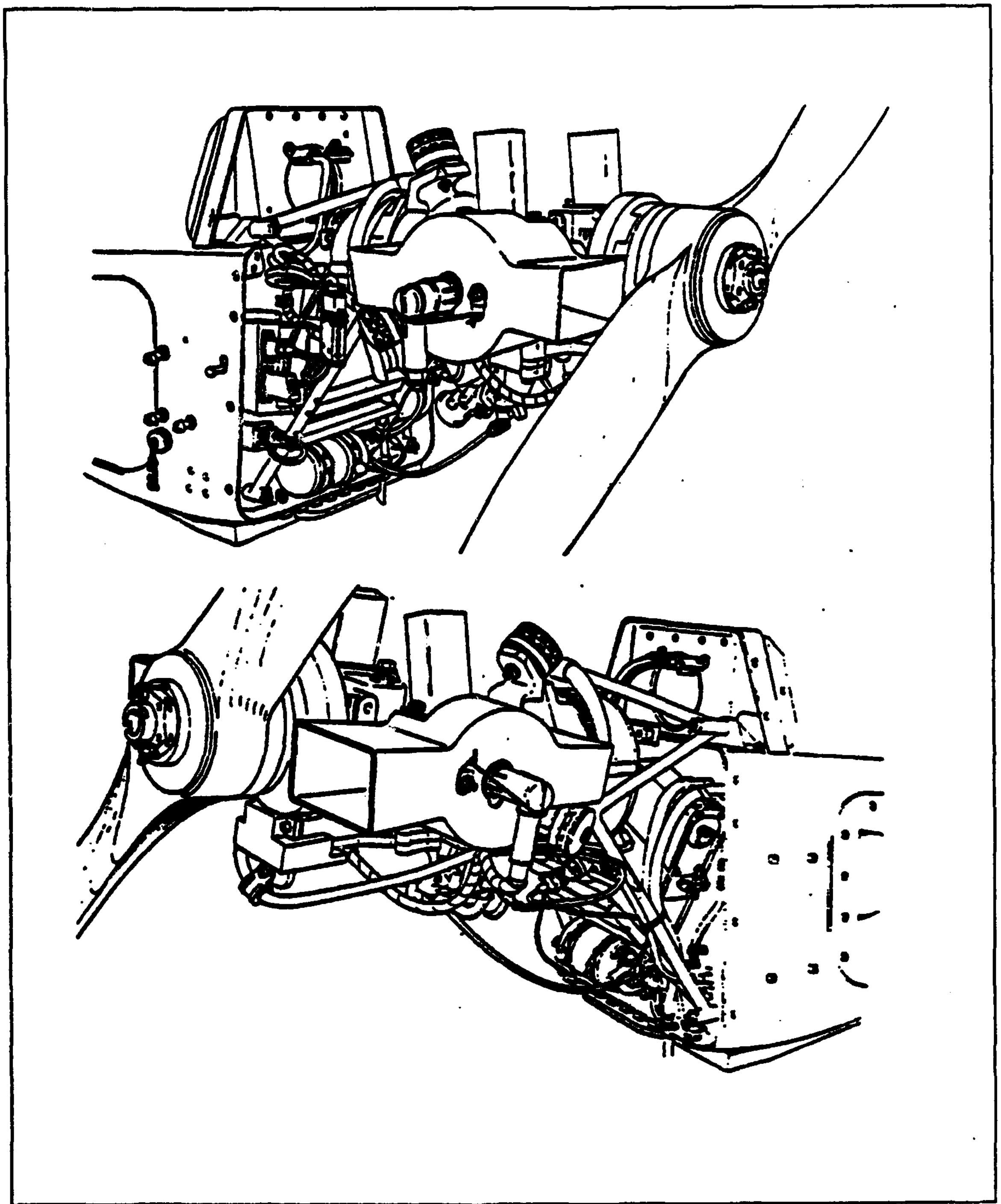


Figure 23. Engine, Left Side View (above), Right Side View (below) (U.S.N. TM Pub No 02E-10, 1990, p. 3-26)

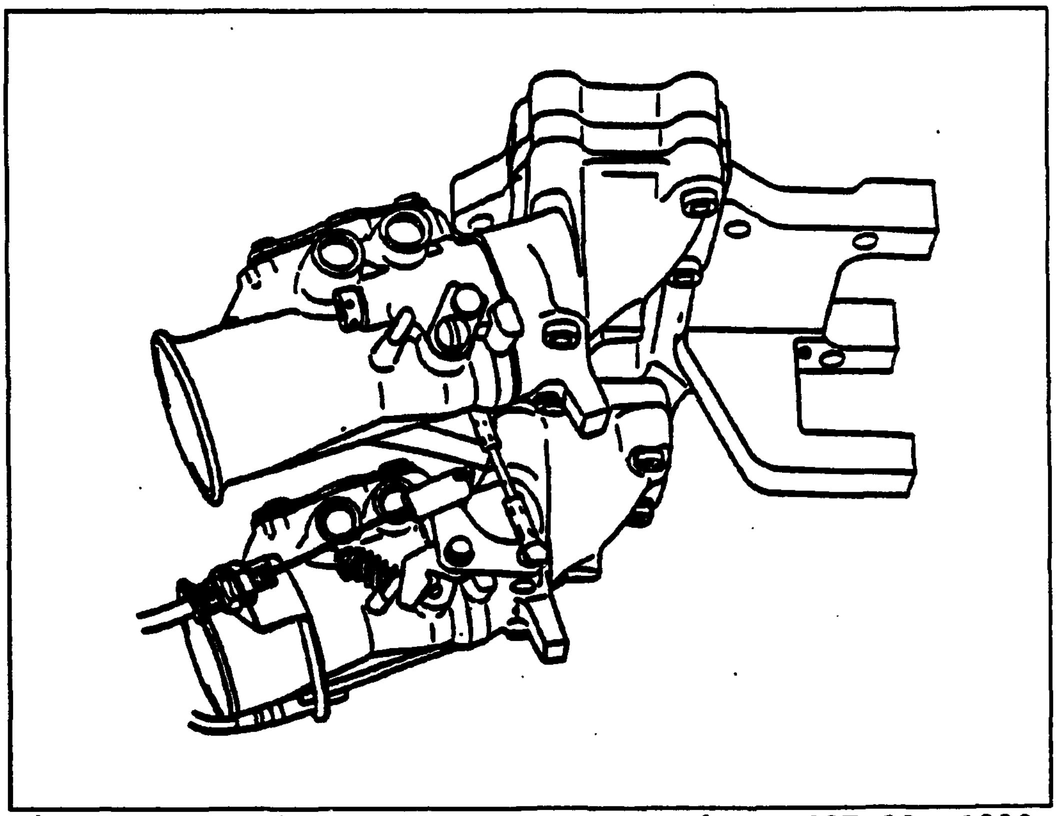


Figure 24. Carburetors (U.S.N. TM Pub No 02E-10, 1990, p. 3-23)

G. CONCLUSION

The Pioneer UAV played a vital role in Operations Desert Shield and Desert Storm. Deployed with six tactical units (three U.S. Marine Corps, two U.S. Navy, one U.S. Army), the Pioneer system flew a total of 682 flights while completing 800 missions. Four hundred twenty-six of those missions were in combat. Nineteen air vehicles were lost with only one Pioneer attrited due to enemy fire. Missions included reconnaissance, targeting, naval gunfire support, artillery adjustment, mine sweeping close air support coordination, and battle damage assessment. The ability of the Pioneer to provide real - time tactical video to the field commander was so successful that the units had more

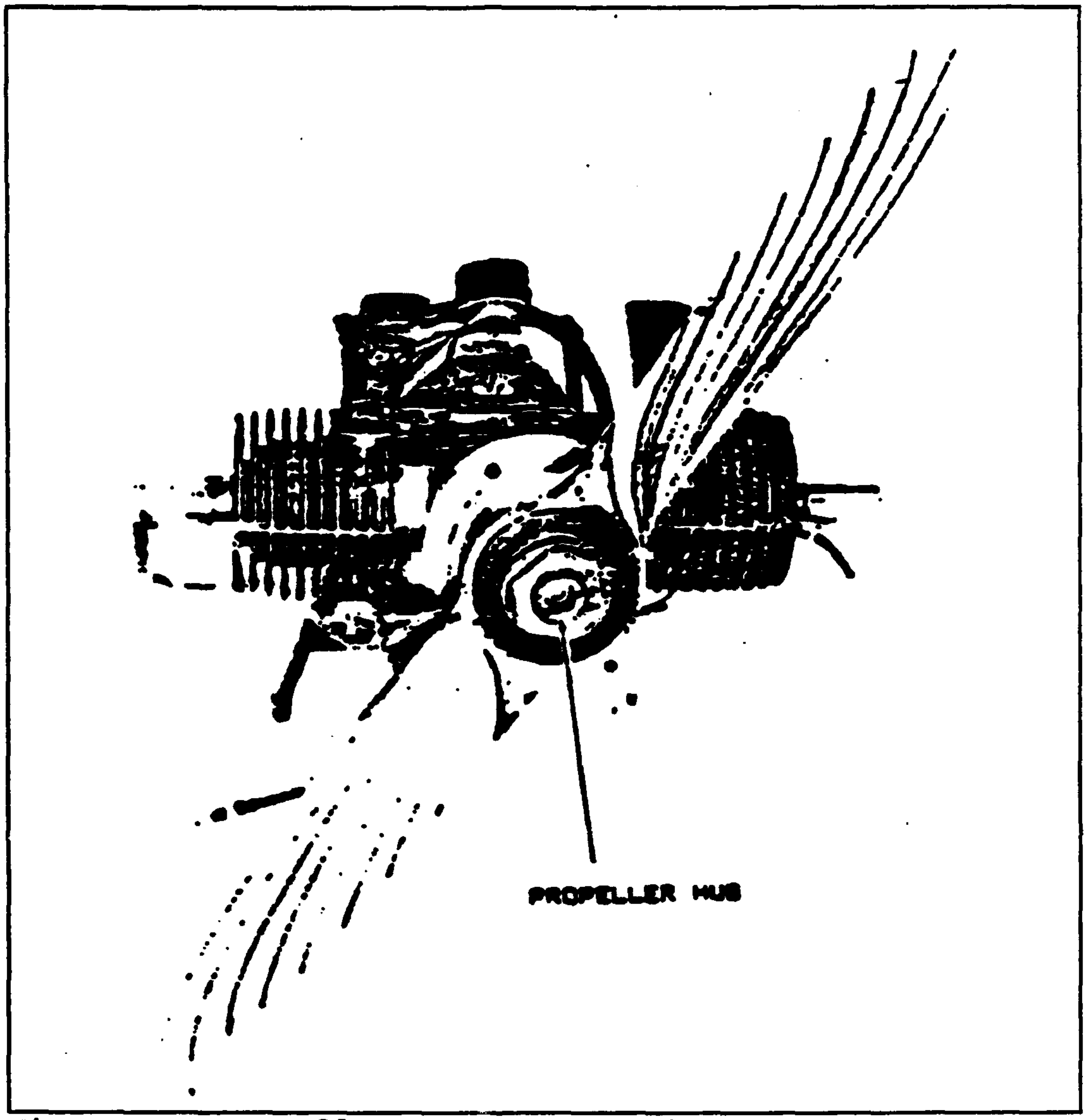


Figure 25. Propeller (U.S.N. TM Pub No 02E-10, 1990, p. 3-29)

mission requests than could be processed. The employment of Pioneer in a combat scenario demonstrates the values of UAVs on the modern battlefield. New tactics and doctrine were developed during the operation and will be expanded during future deployments. The battlefield commander discovered UAVs and their ability to become force multipliers when properly employed. (McCune, 1993, p. 1)

Although UAVs have been around in one form or another for decades, they did not truly come of age until the Pioneer system demonstrated its capabilities during the Gulf War. But the war also showed that there were not enough assets to handle all the tasks battlefield commanders wanted UAVs to support at the rather low sortie rate per vehicle, less than one per day, during the Gulf War. During Operation Desert Storm, Marines from the 1st Marine Expeditionary Force (MEF) led Coalition forces in the number of UAV missions. All three Marine Corps RPV companies supported the Gulf War. Their importance and effectiveness were stressed by all four of the key ground commanders Lieutenant General Boomer, Lieutenant General Moore, Lieutenant General Keys, Major General Hopkins and the overall Marine air commander Major General Myatt. (Dickerson, 1992, p. 97)

The OV-10s (Light Armed Recon Aircraft) are almost gone, and until the F/A-18Ds (all weather fighter/attack jet) get a camera platform, the Pioneer RPV will be the U.S. Marine Corps' primary tactical airborne reconnaissance platform (Dickerson, 1992, p. 97). The military should learn from those combat successes now and push the development of UAV systems. There is no need to wait until the next major regional contingency (MRC) to find out we need UAVs for real-time tactical reconnaissance or other critical missions. (Dickerson, 1992, p. 100)

V. SPREAD SPECTRUM

This chapter provides an overview of spread spectrum communications. The two most common schemes of encoding, direct sequence and frequency hopping are reviewed in depth. The benefits of spread spectrum communications techniques are also discussed.

The common rule of thumb for gauging the efficiency of a communications system modulation scheme is to examine how tightly it concentrates the energy of the signal bandwidth for a given rate of information transmission (bit rate). While the compactness of the signal appeals to the conventional wisdom, spread spectrum coding techniques take the exact opposite approach in spreading the signal over a very large bandwidth. (ARRL, 1994, p. 21-7)

A spread spectrum system is defined as one in which the average energy of the transmitted signal is spread over a bandwidth which is much wider than the minimum bandwidth necessary to transmit the information. Spread spectrum is a coding technique for digital transmission. The purpose of the coding is to transform the information signal into a much wider bandwidth signal that is of a signal strength equal to or less than the ambient noise. If the ambient noise has a flat, uniform spectrum with no coherent peaks, the spread signal can be recovered by receiver processing. The spread spectrum coding technique modifies the signal spectrum to spread it out so that the new spectrum has a much lower power density, but the same total power. (Barnes, 1993, p. 1)

A. SPREADING TECHNIQUES

This section will discuss the two common types of spread spectrum encoding techniques in use. They are Direct Sequence (DS) and Frequency Hopping (FH). Particular aspects such as encoding and decoding, power density, process gain, jamming margin, synchronization and code division multiple access are addressed.

Direct sequence is the name given to the spreading technique whereby a carrier wave is first modulated with a data signal, then the data signal is again modulated with a high-speed (wideband) spreading signal. The spreading pulse stream is a binary sequence designed to appear to be random and is often called a pseudorandum sequence. Such sequences are called pseudo-random (PN). Each bit in the PN code is called a chip. Figure 26 pictures a typical direct sequence transmitter and receiver. The data pulse stream and the spreading pulse stream are first multiplied together, and then the composite signal modulates the carrier. Typically, a binary phase shift keying (BPSK) form of data modulation is encountered. The initial step in the DS/BPSK modulation can be accomplished by the modulo-2 addition of the binary data sequence with the binary spreading sequence. Demodulation of the DS/BPSK signal is accomplished by correlating the received signal with a synchronized replica of the spreading signal. When it is synchronized, the output of the receiver correlator is the despread data-modulated signal. The despreading correlator is then followed by a conventional demodulator for recovering the data. (Sklar, 1988, pp. 549-550)

Another spread spectrum technique called frequency hopping (FH) will be considered. The modulation most commonly used with this technique is M-ary frequency

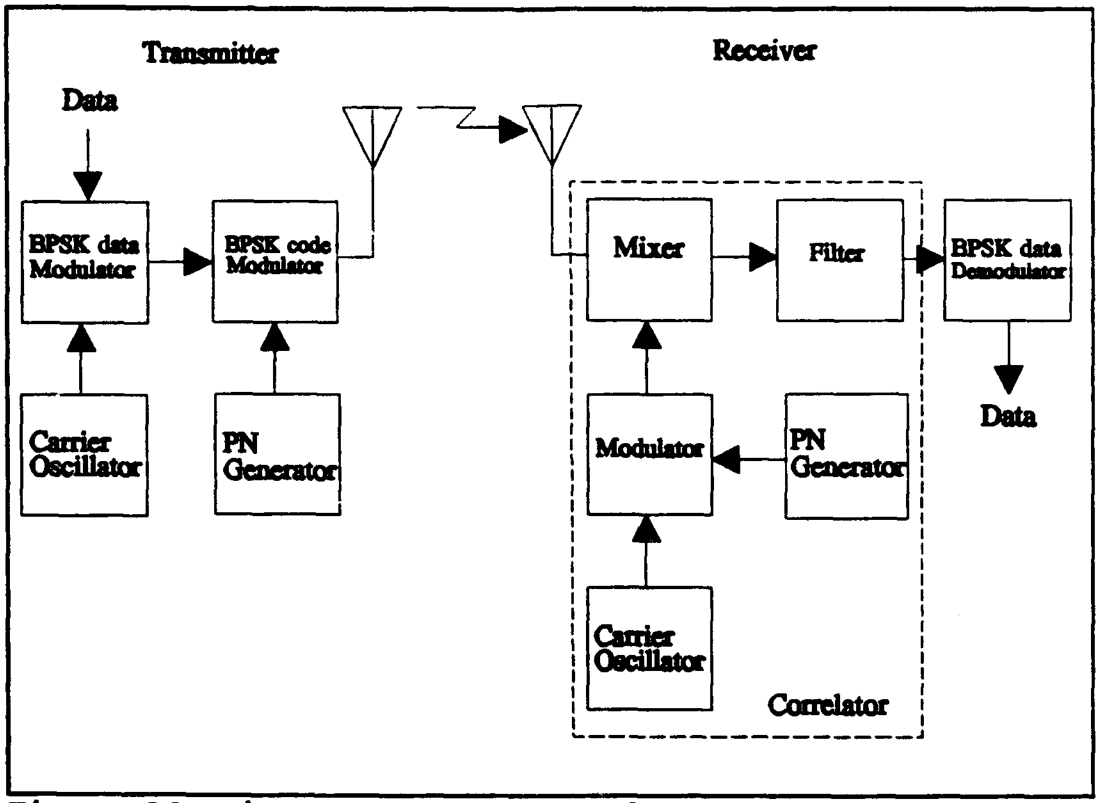


Figure 26. Direct Sequence Spread Spectrum System

shift keying (MFSK), where $k = log_2M$ information bits are used to determine which one of the M frequencies is to be transmitted. The position of the M-ary signal set is shifted pseudorandomly by the frequency synthesizer over a hopping bandwidth. A typical FH/MFSK system block diagram is shown in Figure 27. In a conventional MFSK system, the data symbol modulates a fixed frequency carrier. In an FH/MFSK system the data symbol modulates a carrier frequency whose frequency is pseudorandomly determined. In either case, a single tone is transmitted. The FH system can be thought of as a two step modulation process, i.e., data modulation and frequency hopping modulation, even though it can be implemented in a single step. The frequency synthesizer produces a tone based on simultaneous dictates of the PN code and the data. At each frequency hop time

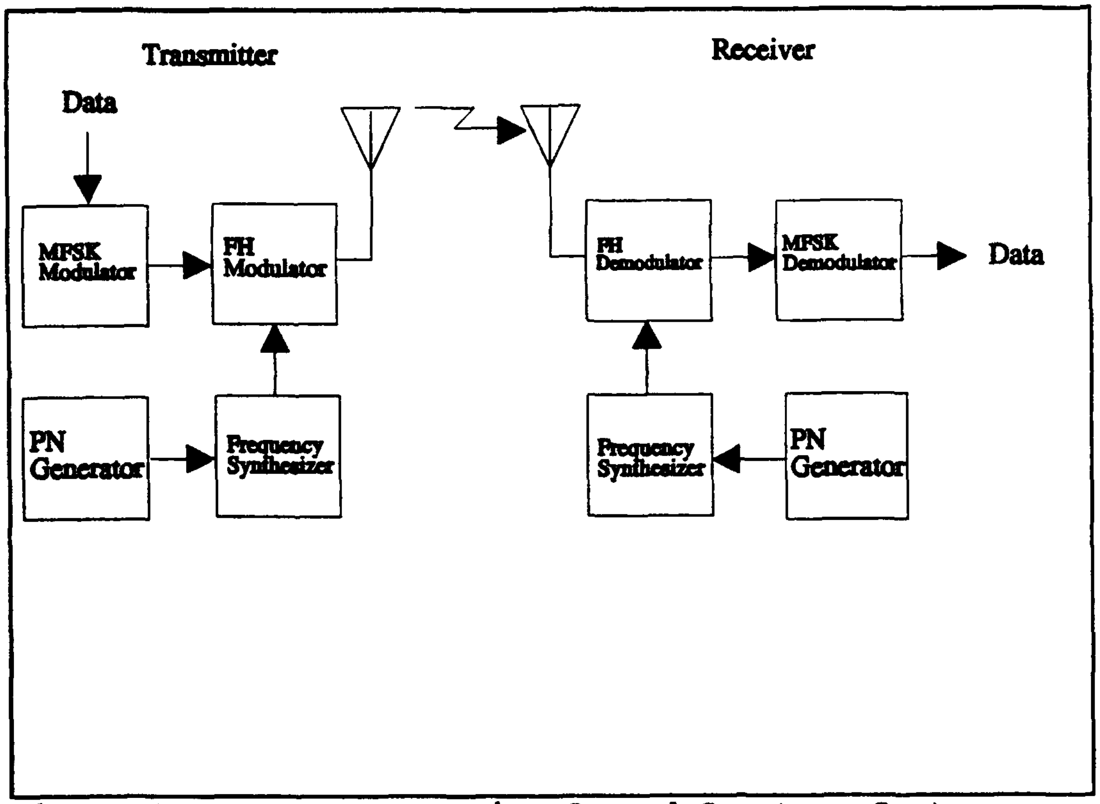


Figure 27. Frequency Hopping Spread Spectrum System

a PN generator feeds the frequency synthesizer a frequency word which dictates one symbol set position. The frequency hopping bandwidth, and the minimum frequency spacing between consecutive hop positions, dictate the minimum number of chips necessary in the frequency word. For a given hop, the occupied transmission bandwidth is identical to identical to the bandwidth of conventional MFSK. However, averaged over many hops, the FH/MFSK spectrum occupies the entire spread spectrum bandwidth. The receiver reverses the process. The received signal is first FH demodulated by mixing it with the same PN selected frequencies used for the hopping. Then the dehopped signal is applied to a conventional bank of M noncoherent energy detectors to select the most likely symbol. (Sklar, 1988, pp. 555-556)

In summary, DS spreads the signal out over a wide bandwidth. The amount of spreading is dictated by a PN code. Its power spectral density is so small that its presence is hard to detect among the ambient noise level. The importance of this point will be emphasized later. In contrast, the presence of a FH can be observed, but the carrier literally hops to another frequency over a wide bandwidth. The new frequency is determined by a PN code that cannot be predicted by an unintended party. The lack of knowledge about what the new frequency is makes it hard or nearly impossible for a jammer to jam the signal. Combinations of the two techniques are referred to as hybrid systems.

1. Encoding and Decoding

Pseudo-random codes have a fixed length. After a given number of bits the codes repeat themselves exactly. Codes may be formed using a shift register with feedback taps. Figure 28 shows a common way of using a 7-bit shift register to generate a series of codes with a length of 127 bits.

There are three randomness properties that make a PN signal appear to be truly random. A description of these properties for binary signals, called balance, run, and correlation, are described below.

> 1. Balance property. Good balance requires that in each period of the sequence, the number of binary ones differs from the number of binary zeros by at most one digit.
>
> 2. Run property. A run is defined as a sequence of a single type of binary digit(s). The appearance of the alternate digit in a sequence starts a new run. The length of the run is the number of digits in the run. Among the runs of ones and zeros in each period, it is desirable that about one-half the runs of each type are length 1, about one-fourth are of length 2, one-eighth are of length 3, and so on.

3. Correlation property. If a period of the sequence is compared term by term with any cyclic shift of itself, it is best if the number of agreements differs from the number of disagreements by not more than one count. (Sklar, 1988, p. 546)

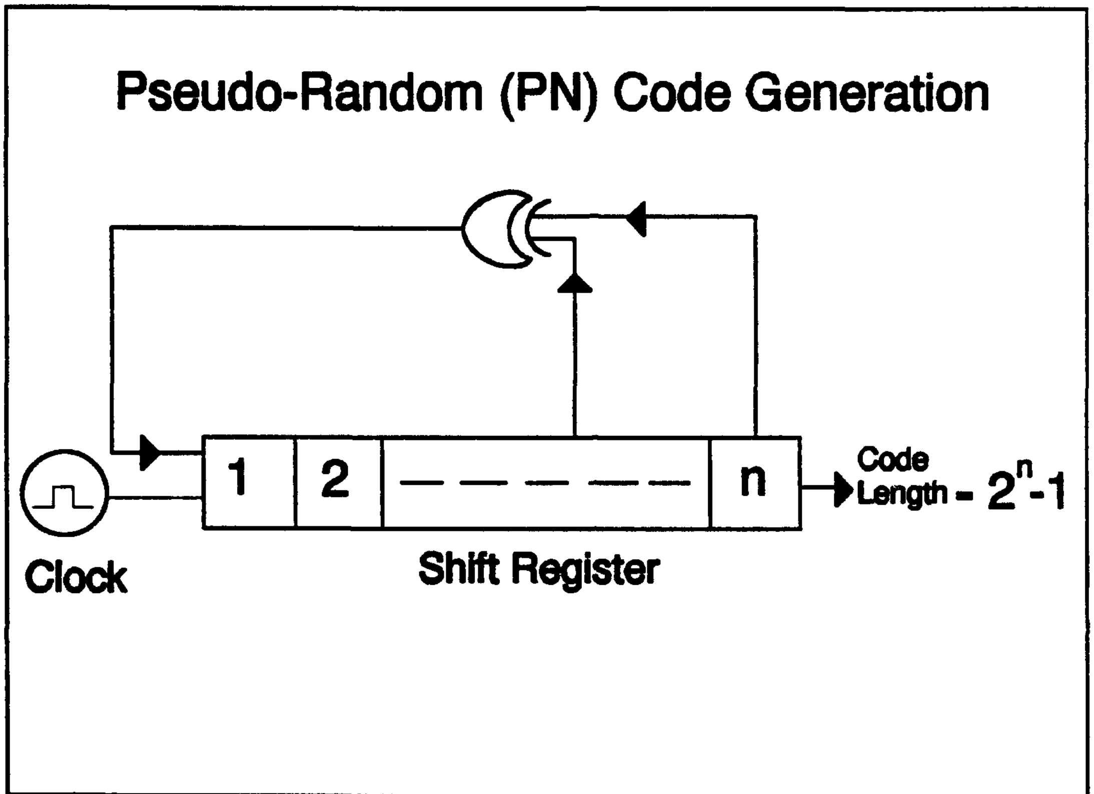


Figure 28. Typical PN code generation technique

Good codes also have a high auto-correlation peak. Exact alignment minimizes false synchronization. Auto-correlation is the number of agreements less number of disagreements in a comparison of one full period of the sequence with a τ position cyclic shift of the sequence. (Sklar, 1988, p. 548) The two most common code families are the m-sequence and the Gold codes. Gold codes are a family of spreading codes generated by Exclusive-OR combining the output of two preferred m-sequence generators. An important consideration in choosing a PN sequence for a spread spectrum system is the amount of statistical similarity a sequence has with conventional signals and with sequences employed by other spread spectrum systems. (ARRL, 1994, p. 21-12)

2. Synchronization

The most difficult part of designing a spread spectrum system is ensuring fast and reliable receiver synchronization. Receiver synchronization is the process of receiver's own internally generated PN sequence matching up exactly with the demodulated received PN sequence generated at the transmitter. The receiver correlation process removes the spreading code and the demodulator recovers the information at the baseband. Both operations must be synchronous with the transmitted signal and will usually lock up to the incoming signal and track it. Acquisition time is the period taken to lock up the receiver from a cold start and is one measure of the receiver's performance. Other measures include the ability to synchronize in the presence of interference and/or thermal noise and to remain synchronized over long periods. (Barnes, 1993, p. 4)

3. Power Density

Power density is highest in an unmodulated carrier (i.e., all the RF output power is present in a narrow bandwidth around the carrier). Modulated signals have different power densities. Spread spectrum signals attempt to produce a completely uniform power density with no peaks by using pseudo-random chip sequences. The closer that the sequence comes to being random, the more uniform the power density. Spread spectrum signals never achieve a completely uniform power density and will always exhibit a line structured spectrum. The frequency separation of the line spectra is reduced by increasing the code repetition rate (higher chip rate and/or longer pseudo-random codes). (Barnes, 1993, p. 2)

4. Process Gain and Jamming Margin

Spread spectrum systems achieve a "process gain" by exceeding the Shannon bandwidth[1]. Process gain in direct sequence system is a function of the RF bandwidth of the signal transmitted compared with the bit rate of the information. Process gain is determined by the equation

$$G = B / R$$

where G is the process gain, B is the RF bandwidth and R is the data rate. Process gain can be thought of as the desired signal strength over noise, or jamming, advantage that the spreading process provides. The usual assumption taken is that the RF bandwidth is that of the main lobe of the $[(\sin x)/x]^2$ direct sequence spectrum, which is 0.88 times the chip rate. Therefore, for a system having a 10 M cps chip rate and a 1 kbps information rate, the process gain would be $(0.88 \times 10^7) / (1 \times 10^3) = 8.8 \times 10^3$ or 39 dB. Such parameters are typical for practical systems. (Dixon, 1984, p. 25)

Jamming margin is the capability of a system to perform in a hostile environment. The jamming margin is effectively the process gain, allowing for implementation losses and a minimum acceptable output signal-to-noise ratio,

$$J = G - (L + S)$$

[1] In 1948-1949, Claude Shannon derived a theoretical system with no bit error rate. He showed that channel capacity (C) could be calculated such that if the rate of information was less than C, the probability of error would approach zero. $C = B \log_2(1 + S/N)$ (Couch, 1993, pp. 20-21)

where J is the jamming margin, G is the process gain, L is the system implementation losses and S is the minimum output signal-to-noise ratio. Jamming margin measurements reveal the efficiency of a spread spectrum receiver. Some receiver designs may realize none of the available process gain because post detection correlation is used. To achieve a jamming margin improvement, an efficient receiver design incorporates preprocessing correlation. An example would be a QPSK, direct sequence spread spectrum system with 11 dB available process gain with 0 dB implementation loss. With a S/N ratio of 13 dB for QPSK at a BER of 1×10^{-6}, a jamming margin of - 2 dB is obtained. A "good" spread spectrum receiver need not have a positive jamming margin to be considered adequate. (Barnes, 1993, p. 3)

5. Code Division Multiple Access (CDMA)

Multiple access techniques allow multiple signals occupying the same RF resource bandwidth (i.e., channel, spectrum, satellite, etc.) to be transmitted simultaneously without interfering with one another. Multiple DS spread spectrum systems using different PN codes can use the same RF bandwidth. Because the PN codes are orthogonal, the cross-correlation of two different codes is near zero, and the multiple users simply appear as extra background noise to one another. This is called code division multiple access, or CDMA, because all the participants can share the full spectrum of the resource asynchronously. The transition times of the different users' symbols do not coincide. (Sklar, 1988, p. 571) Because each transmitter appears as a noise source to the others, CDMA can be implemented only if an adequate jamming margin exists. The CDMA receiver is able to synchronize to one of the multiple signals being received and the desired spreading process greatly attenuates the remaining signal paths. The number of users is determined by

$$E_S / N_J = 2G_P /(L - 1)$$

where E_S is the desired signal strength, N_J is the strength of the noise level or jammer, G_P is the receiver processing gain and L is the number of users.

The most common spread spectrum encoding techniques are direct sequence and frequency hopping. Spread spectrum encoding uses a binary PN sequence to give the signal a pseudorandom appearance. Acquisition time due to receiver synchronization is an important aspect of a spread spectrum receiver design. The power spectral density of a direct sequence signal is less than that of ambient noise. This trait gives the signal a low probability of detection (LPD) by an unintended receiver. The process gain and jamming margin of spread spectrum signals afford the user a low probability of exploitation (LPE) by any undesired party (e.g., a jammer). Spread spectrum allows multiple users to occupy the same spectrum bandwidth without interference through use of CDMA.

B. BENEFITS

The section discusses some of the benefits of spread spectrum communications. Aside from having a neglible spectral signature, spread spectrum communications provide an unconscious reliance to the user that not only will the signal get through, but it won't be tampered with in the process. Additionally, the benefits associated with spread spectrum provide new capabilities to the user other than just talking back and forth or sending data. These capabilities include transmission security, interference rejection, multipath rejection, range measurements, direction finding and near-far performance.

1. Transmission Security (TRANSEC)

TRANSEC deals with making communications signals maximally useful to the intended communications users and minimally susceptible to either jamming or exploitation by parties unfriendly to the communicators. Against exploitation the goal of TRANSEC is to provide the communications signals with an ability to lower the probability of successful signal detection, feature extraction, interception, and message-recovery operations which could otherwise result in a negative impact on communicators. TRANSEC signals with this ability are said to have a low probability of exploitation (LPE). (Nicholson, 1988, p. 2)

The Mathematical Theory of Communication written by Claude E. Shannon in 1948, and often times referred to as Shannon's Information Theory, provided several lessons which apply to digital communications. The essence of one of Shannon's lesson that typifies the underlying motive of signal exploitation follows:

> In the presence of interference or jamming, intentional or otherwise, the communicator, through signal processing at both transmitter and receiver, can ensure that performance degradation due to the interference will be no worse than that caused by Gaussian noise at equivalent power levels. This implies that the jammer's optimal strategy is to produce Gaussian noise interference. Against such interference, the communicator's best waveform should statistically appear as Gaussian noise. Thus, the "minimax" solution to the contest is that signals and interference should all appear as noise which is as wideband as possible. This is a particularly satisfying solution when, as we shall see, one user's signal is another user's interference. (Viterbi, 1991, p. 34)

Against unfriendly jamming, the goal of TRANSEC is to provide the communications receiver with an ability to maintain good performance during a jamming attack. TRANSEC communications of this type are said to provide good anti-jam (AJ) protection. Detection is the process of choosing between signal plus noise and noise alone. One measure of the ability to detect signals is probability of detection (P_d). Hidden signals which make it difficult for unintended receivers to detect them are said to have a low probability of detection (LPD). Denying an unintended intercept receiver the features of signals that could be used to distinguish between the signals is called providing the signals with a low probability of intercept (LPI). (Nicholson, 1988, pp. 3-4) LPI originates from the need to synchronize the receiver's PN sequence with the transmitter. These TRANSEC benefits have made spread spectrum very attractive for military communications since the 1950s. TRANSEC allows spread spectrum equipped UAVs to operate covertly in hostile territory while performing missions. (Campana, 1993, p. 13)

2. Interference Rejection

The processing gain of a spread spectrum system is defined as the ratio of the post processing bandwidth to the rf bandwidth. The strength of an interfering signal at the receiver output is reduced by the processing gain. This feature has a limit. The desired spread spectrum signal will not necessarily "get through" when the interfering signal has a power greater than the desired signal by the amount of the processing gain. When the external signal is multiplied by the receiver's PN sequence, it will be spread rather than despread. This is a feature that is not possible with conventional narrowband systems. Interference rejection offers a UAV immunity to intentional enemy jamming as well as friendly EMI. (PENEX, 1993, pp. 7-8)

3. Multipath Rejection

Conventional narrowband systems are limited by an effect known as multipath interference. When a transmitted signal propagates toward a receiver, several paths may exist which may cause this interference due to a phase cancellation at the receiver. This is called multipath propagation. If the signal propagated via the ionosphere, the path delays can range from tens of microseconds to several milliseconds. Similar multipath delays can exist at VHF and UHF frequencies due to reflections from buildings, towers and other reflective materials. Multipath signals can actually be considered a special case of unintentional jamming.

Frequency hopping concentrates the signal power at discrete frequencies for short periods of time. If the carrier jumps to a frequency where a multipath null resides, data will be lost until the next frequency hop. In fast frequency hopping (FFH), each data bit is transmitted at several different frequencies, and since it is unlikely that nulls occur at most of these frequencies, a measure of multipath immunity is gained. On the other hand, if slow frequency hopping (SFH) is used in an environment with multipath nulls, burst error correction is essential. Direct sequence systems offer a higher degree of multipath rejection than frequency hopping systems by spreading the same data over a wide bandwidth simultaneously rather than one discrete frequency at a time. Multipath rejection is essential to an autonomous UAV flying in a wide variety of topographies. Reflections from the sea surface would be prominent in an offshore naval scenario.

UAVs employing direct sequence spread spectrum would maximize this benefit. (ARRL, 1991, p. 4-16) (Campana, 1993, p. 15)

4. High Resolution Range Measurements

Rf signals are subject to a fixed rate of propagation (approximately 6 μsec per mile). Since the velocity of propagation is known, and the path length between a transmitter and a receiver is defined, uncertainties in the measurement of the arrival time of a particular mode at the receiver are inversely proportional to the signal bandwidth. A common type of echo range measurement method is that used in radar systems. Many such systems transmit a pulse of rf energy and then wait for the return of a portion of the energy due to its being reflected from objects in the signal path (i.e., echoes). The radar system marks the time from pulse transmission to receipt of its echo. This time difference is a function of two-way range (out and back), known as a radar range. Because the propagation rate is known, the range is easily calculated. Any signal used is subject to the same distance / time relations. Spread spectrum has an advantage over CW and other forms of carriers in that its phase is easily removable. The identity of a direct sequence system is in its encoding sequence. The basic resolution is one code chip. The higher the chip rate, the more accurate the distance measurement capability. Frequency hopping systems do not normally possess high-resolution properties, due to the fact that their hopping rates are not high enough. This benefit of spread spectrum improves the accuracy of a UAV to autonomously fly to waypoints. Additionally, more accurate positional location information could be available for targeting. This feature is a basic concept behind Differential GPS (DGPS). DGPS provides more accurate navigational fixes than the conventional GPS. (Dixon, 1984, pp. 291-292)

5. Direction Finding

The accuracy of direction finding when using a two or three antenna array is determined by two parameters; the distance between the antennas and the degree to which the distance can be resolved as received by the processors attached to the antennas. Many direct sequence systems can resolve ranges to within one-tenth clock chip, and some can do as well as one-thousandth chip. But typically with two antennas, this chip fractions equate to a maximum resolvable distance increment which is still not adequate for realistic applications. A way to improve this would be to physically separate the two antennas. Some platforms cannot practically realize this required antenna separation. An alternative to separation of two physical antennas would be a time separation of measurement. However, with this option, it would be difficult to resolve bearing ambiguity. Frequency hopping systems are penalized by even slower hopping code rates. Spread spectrum systems can provide range measurements over any range that the receiver will synchronize. Furthermore, the range resolution is never worse than a small fraction of the code chip period. The capability of improved accuracy direction finding would allow UAVs with ESM packages to passively locate and then covertly target enemy units. (Dixon, 1984, pp. 311-312)

6. Near-Far Performance

The near-far problem most commonly arises when two or more remote spread spectrum transmitters are communicating with a single receiver. Consider the case when there are multiple transmitters using different codes, but overlapping in frequency and time. The receiver effectively increases the power of the desired signal by an amount equal to the processing gain. However, if the residual noise level exceeds the level of the desired signal, the desired signal will still be "drowned out" by the other transmitted signals. This occurs most often when the desired signal's transmitter is physically much farther away than other interfering transmitters. Frequency hopping systems provide better near-far performance than direct sequence systems. Near-far performance is an important consideration when operating a system of multiple UAVs simultaneously. (Campana, 1993, p. 14) (ARRL, 1991, p. 4-17)

Spread spectrum communications offers several benefits to the user. These benefits are essential if not critical to the successful C^2 process of a warfare commander. The ability to reject unwanted signals while ensuring the desired information gets transmitted to and properly received by the intended receiver is paramount. Spread spectrum offers the assurance that its presence will have a low probability of recognition (LPR), while also maintaining the reliance that the intended signal will have a low probability of exploitation (LPE) by any unintended party.

VI. DATA LINK DEVELOPMENT

This thesis develops an anti-jam, wireless data link to provide connectivity between an onboard computer in a Naval Postgraduate School (NPS) UAV and a ground based computer terminal. As learned in the previous chapters, the UAV can be a tremendous asset to the warfare commander. The ability of the UAV to gather information and relay it back to the warfare commander in real time, can provide the commander a decisive advantage over the enemy. This real time snapshot allows the commander to operate up the C^2 process faster than with more conventional time-late forms of intelligence. Realizing that the battlespace is a hostile environment to both humans and equipment, a method of relaying the data from the UAV to the commander must be immune to exploitation by undesired parties. Spread spectrum communications can provide this immunity. Not only can spread spectrum achieve substantial jamming margins, but its signal can offer a low probability of detection by masking its presence in ambient noise levels.

The particular aircraft targeted for data link implementation was the NPS Navy Blue Bird pictured in Figure 29. Hereafter, it will be referred to as the "Blue Bird". The requirement for the NPS proof-of-concept project, was to supply a bidirectional data link for a UAV such as the Blue Bird. The data link should allow the UAV to have a nominal operational range of approximately forty miles. The airborne components must be small, lightweight and capable of being powered by a battery system. These three factors could encumber the aircraft. The data link must be capable of an initial data throughput of 19.2 kbps. For ease of interface to other COTS computer hardware, the link had to conform to an RS-232 standard interface. The link had to be capable of being enabled and configured by the use of a "C" programming language. Once enabled, the link must be transparent to the computers at each end (i.e., on the UAV, and at the ground terminal). And lastly, all hardware for the link had to conform to a project budget of approximately $3000.00. Factors critical to this attempt's success would be size, weight, power consumption, heat generation, interference immunity, data throughput, interoperability and compatibility with adjacent components, reliability, COTS availability and cost.

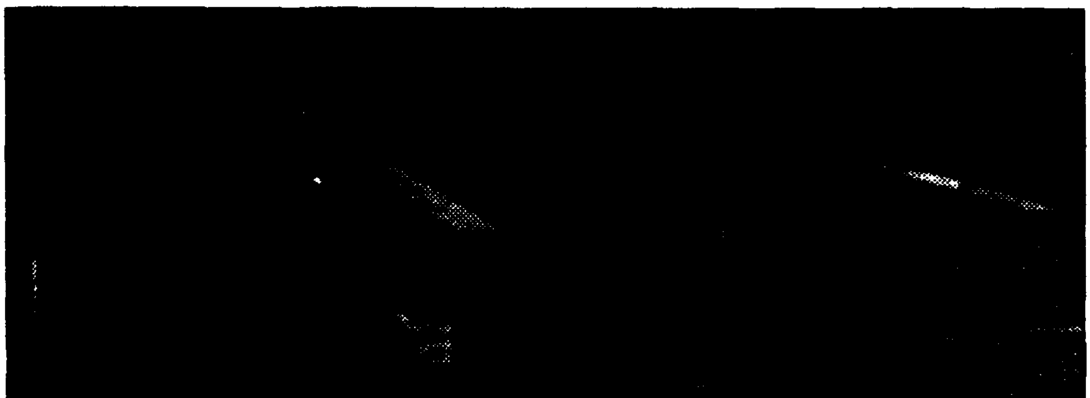


Figure 29. NPS Navy Blue Bird (Note: U.S. NAVY letters are 4" tall) (Meeks, 1993)

A. DATA LINK DEVELOPMENT

The previous NPS UAV data link consisted of an Amateur Radio (i.e., ham radio) packet radio terminal node controller (TNC) and a 450 MHz (70 cm) band transceiver at each end of the link. While the equipment was relatively small and light weight, modestly priced and COTS, it required an Amateur Radio License for its operation. The link establishment procedures and commands were not extremely user friendly for the non-packet operating, non-amateur radio operator. The proof-of-concept link was tested in a fixed, static environment. The link was configured for 19.2 kbps and successfully yielded an asynchronous data throughput of approximately 14 kbps. (Reichert, 1993, pp. 44-47)

A spread spectrum data link was considered to minimize the potential of jamming. The UAV will be eventually operate in a hostile environment where the enemy will maximize the use of signal exploitation. Currently the ISM band allows FCC license free operation of spread spectrum equipment. Operating in this band with specific FCC type accepted or approved spread spectrum equipment would ease testing and operating burdens on the UAV project by alleviating the necessity of having a licensed amateur radio operator in control of the data link at all times, as was the case in the previous NPS data link. Adopting a data link with some form of packet protocol would enhance interoperability with COTS computer interfaces.

1. Federal Communications Commission Licensing

The regulatory basis of Part 15 spread spectrum links is provided by the Federal Communications Commission (FCC) Rule Part 15.247. This was an initiative by the FCC to authorize the use of spread spectrum transmitters without requiring individual user licenses and was intended to promote the use of new technology. Transmitters operating under Part 15.247 may intentionally radiate only in the Industrial Scientific and Medical (ISM) band, and may only use frequency hopping or direct sequence techniques.

No other spreading techniques are permitted. There are three microwave frequency bands allocated to this service: 902 - 928 MHz, 2400 - 2483.5 MHz and 5725 - 5850 MHz. Spread spectrum transmitters operating under FCC Rule 15.247 must meet certain technical standards as well as meeting all the general provisions of the FCC Part 15 Rules. The technical standards for direct sequence spread spectrum systems include a maximum transmitter Effective Isotropic Radiated Power (EIRP) which is limited to +6 dBW (1 watt into a 6 dBi gain antenna). However, users may take advantage of transition provisions under which the EIRP limit is modified to a 1 watt rf output power into any antenna. Products that are certified by June 23, 1992 and manufactured up until June 23, 1994 fall under the transition provisions and equipment users with these products can operate at this power level indefinitely. Part 15 equipment operates on a secondary basis: users must accept interference from other transmitters operating in the same band and may not cause interference to other non-users in the band. (Barnes, 1993, p. 5)

a. Technical Specifications (Direct Sequence Spread Spectrum)

Particular requirements for ISM band operation are as follows:

- Operating frequencies: 902 - 928 MHz
  2400 - 2483.5 MHz
  5725 - 5850 MHz
- Transmit power: 1 watt (+30 dBm)
- Process gain: 10 dB (minimum)
- Transmission power density: + 8 dBm (maximum, in any 3 kHz segment)
- Occupied bandwidth: 500 kHz minimum

- EIRP: 1 watt (+6 dBW) into a 6 dBI gain antenna (or 1 watt into any antenna after June 23, 1994)

b. ISM Band Interferers

Since spread spectrum links share the ISM band, other co-users present possible sources for interference. In the 902 - 928 MHz band, other users include automatic vehicle locators, industrial heaters, microwave ovens, diathermy machines, and military radars. In the 2400 - 2483.5 MHz band, other co-users include microwave ovens and point-to-point links. In the 5725 - 5850 MHz band, point-to-point links also occupy the band. (Dixon, 1993, p. 4)

B. SELECTED SOLUTION

A survey of COTS spread spectrum equipment was conducted. The field of possible candidates was narrowed to three units. Table 1 lists the three units that were evaluated. Based on the project criteria and the data presented in Table 1, item 2, the GINA 6000V was selected for procurement. The critical factors in this decision were weight, power consumption, spreading mode, and unit cost. Item number 3, the Utilinet, was eliminated due to its cost and the fact that it uses slow frequency hopping. Multipath interference could, at times, be a significant problem in UAV applications. Recall that frequency hopping systems feature only limited multipath immunity. Their performance in this respect is very similar to its ability to reject jamming. In fact, multipath signals can be considered as a special case of unintentional jamming. If the carrier jumps to a

TABLE 1. COTS SPREAD SPECTRUM EQUIPMENT

Item	1	2	3
Unit	Airlink 64, RS 232	GINA 6000V	Utilinet WAN Gate
Supplier	Cylink Sunnyvale,CA	GRE America, Inc Belmont,CA	Metricom,Inc. Los Gatos,CA
Spreading Mode	DS	DS	Slow FH
Carrier Frequency	902 - 928 MHz	902 - 928 MHz	902 - 928 MHz
Data Rate	19.2 kbps	2.4-19.2kbps	9.6 kbps
System Gain	125 dB	126 dB	N/A
Buffer Size	N/A	24 k	128 k
Protocol / CRC	N/A	Modified X.25	Packet
Interface	RS-232 DB25	9 pin D Sub RS-232	RS 232
Weight	8.5 lbs.	1.25 lbs	6.25 lbs
Size	2.125"H x8.5"W x10.5"L	1.52"H x4.17"W x5.0"L	6.75"H x11.82"W x 9.30"L
Power	110vac @ 20 W or ± 12vDC, + 5vDC	12vDC, Rec:450mA Xmit:800mA	12vDC, Rec:500mA Xmit:1.2A
Delivery	30 to 45 days ARO	1 week ARO	4 - 6 wks ARO
Cost	$2,700.00 each (including software)	$824.00 each (including software)	$1,800.00 each plus $500.00 for software

frequency where a multipath null resides, data will be lost until the next frequency hop. In fast frequency hopping, each data bit is transmitted at several different frequencies, and since it is unlikely that nulls occur at most of these frequencies, a measure of multipath immunity is gained. On the other hand, if slow frequency hopping is used in an environment with multipath nulls, burst error correction is essential. This reliance on error correction causes the data transmission to slow down and the buffer fills quickly with the eventual loss of data. Item number 1, was not selected on the basis of its weight, power requirements, delivery schedule and cost.

C. THE GINA 6000V

The Global Integrated Network Access (GINA) was designed and manufactured by GRE America, Incorporated in Belmont, California. The GINA, as pictured in Figure 30, was designed as a stand-alone, UHF data transceiver that uses spread spectrum encoding. With a size of 1.52" high x 4.17" wide x 5.0" deep and weighing 1.25 pounds, GINA was intended to be a small, lightweight data terminal / transceiver. Drawing less than 10 watts from a 10.5 to 13.8 volt DC source, and having an operating temperature range of -25 to +60 degrees Centigrade, GINA can be adaptable to many environments. The GINA 6000V unit houses three circuit cards which contain the following sections: RF, digital and spread spectrum, and control. A block diagram of the GINA 6000V appears in Figure 31. The transmitter, receiver and PLL subsections are shared between both the RF and digital and spread spectrum circuit cards. Additionally the digital card holds the PN generator. The transmit and receive data pass between the digital and spread spectrum

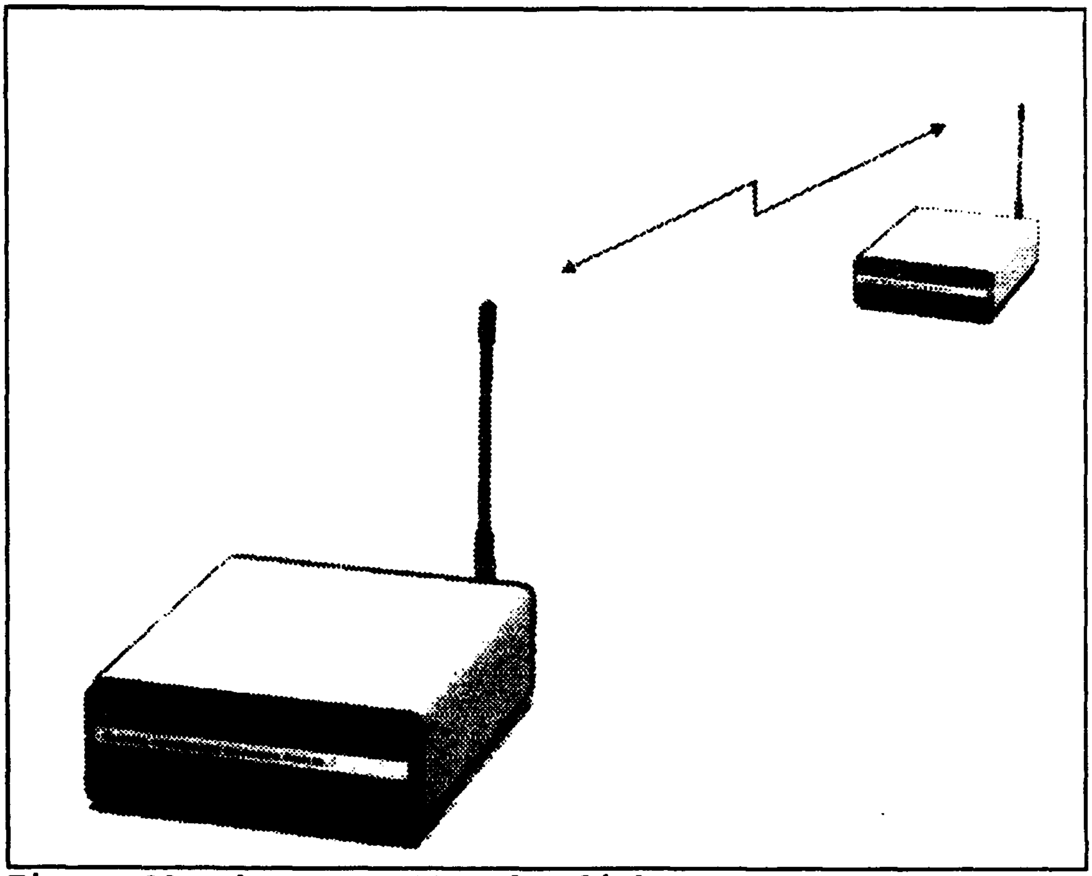


Figure 30. The GINA 6000V datalink (GINA, 1993, p. 1)

card and the control card. The control card holds the CPU, ROM, RAM and serial interface. The serial interface provides the path and conditioning between the GINA and its associated computer. The CPU controls the entire data interface, buffering, retransmission and error correction process. The ROM holds the initial link configuration parameters. The RAM serves as a temporary storage and buffers the data between the over the air RF transmission process and the hardwired data interface to the computer.

The transmitter has an output power of + 30 dBm (1 watt) maximum. It has a 50 ohm connection to the antenna via an SMA type connector. The 6000V is shipped with a rubberized, flexible sleeved one half wave dipole (i.e., "rubber duck"). This antenna

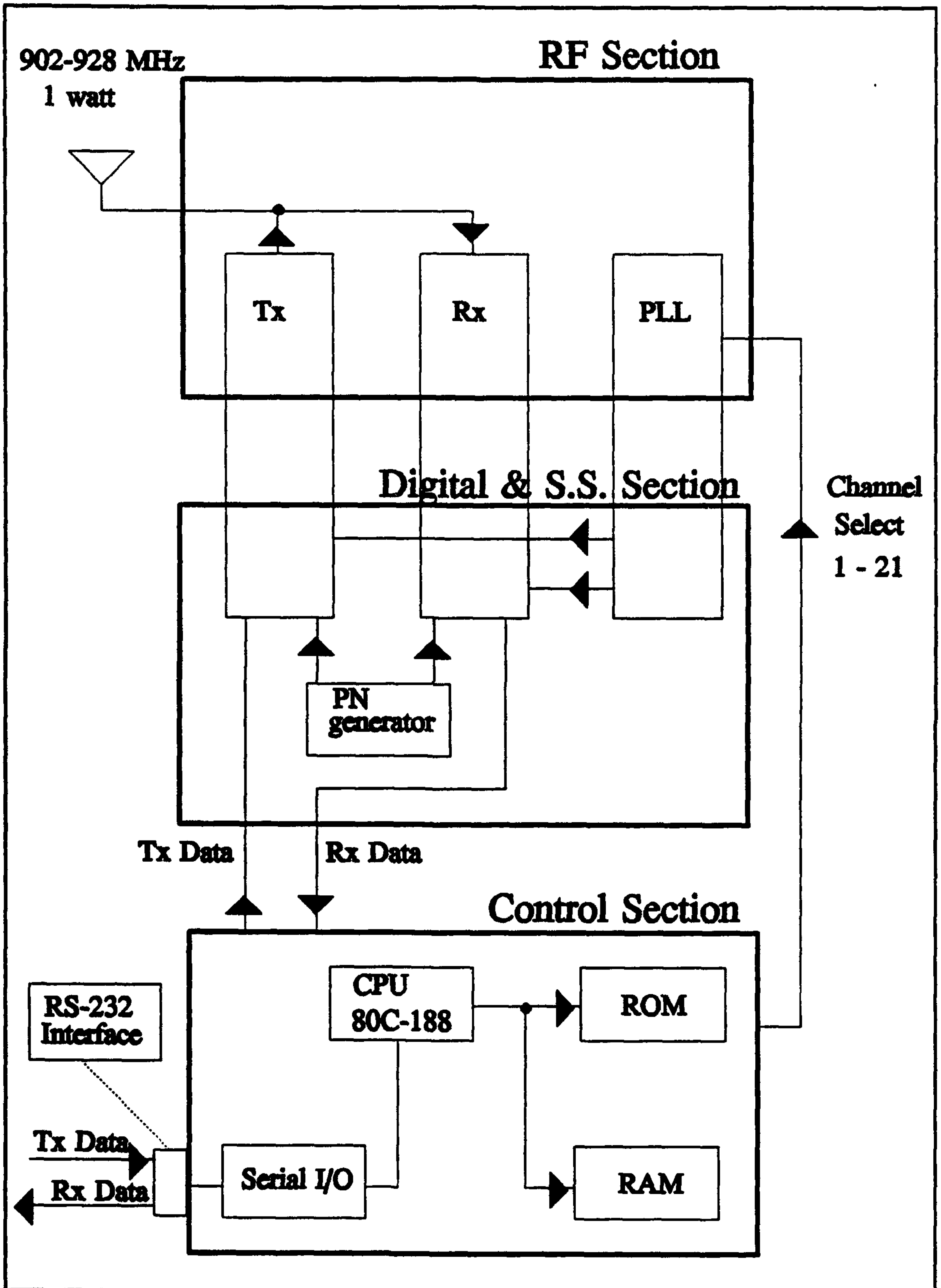


Figure 31. The GINA 6000V block diagram (Takahashi, 1993)

offers a gain of 2.13 dBi. The frequency range is software selectable from 902 MHz to 928 MHz in 1 MHz steps. The carrier stability is $\pm$ 15 kHz. The carrier frequency, as well as all operating parameters, can be changed from a computer via the I/O interface. The control card sends the PLL a channel select signal. The PLL then creates the reference frequency for the transmitter. The modulation is BPSK with direct sequence spread spectrum encoding. The transmitter gets its spreading code from the PN generator on the digital and spread spectrum card. The PN chip rate is 2 MHz with a PN code length of 127 chips from a 7 stage generator. The unit comes equipped with a front panel orderwire option to allow voice communication between units. While in the transmit mode the unit draws 800 mA at 12 volts DC.

The receiver has the same frequency range and increments as the transmitter. The frequency is determined the same way that it is for the transmitter, the control card sends a channel select to the PLL and the PLL serves as a reference oscillator for the receiver. The PN generator supplies a reference signal to the receiver for correlation with incoming received signals. It shares a common antenna with the transmitter. The receiver has a sensitivity of - 103 dBm. It has a designed processing gain (G_P) of 32 dB. It has a signal acquisition time of 8 ms with a data bit error rate (BER) of 1×10^{-6} with a - 95 dBm input signal level. The local PLL oscillator stability is rated at $\pm$ 15 kHz. In the receive mode, the unit draws 450 mA at 12 volts DC.

The controller has a 30 feature software programmable configuration. It uses an 80C188 16 bit CPU chip. Its program memory is contained in a 64k byte ROM. Its data memory is contained in a 32k byte RAM. Its packet size, among other features, is program adjustable from 5 to 255 bytes. It has real time clock with a battery backup. The manufacture provides a DOS executable program called GTALK with the units to be used for configuration programming and terminal operation. GTALK is written in Assembly and C languages. The GTALK menu flowchart is depicted in Figure 32. GTALK has a display configuration option that allows the user to monitor the status of all the system parameters. A sample configuration appears in Table 2.

The GINA 6000V uses a modified X.25 protocol. It uses High Le... Data Link Control (HDLC) in its level two data link layer. Cyclic redundancy check (CRC) error detection is employed, specifically CRC - 16[2]. Stop and wait automatic repeat request

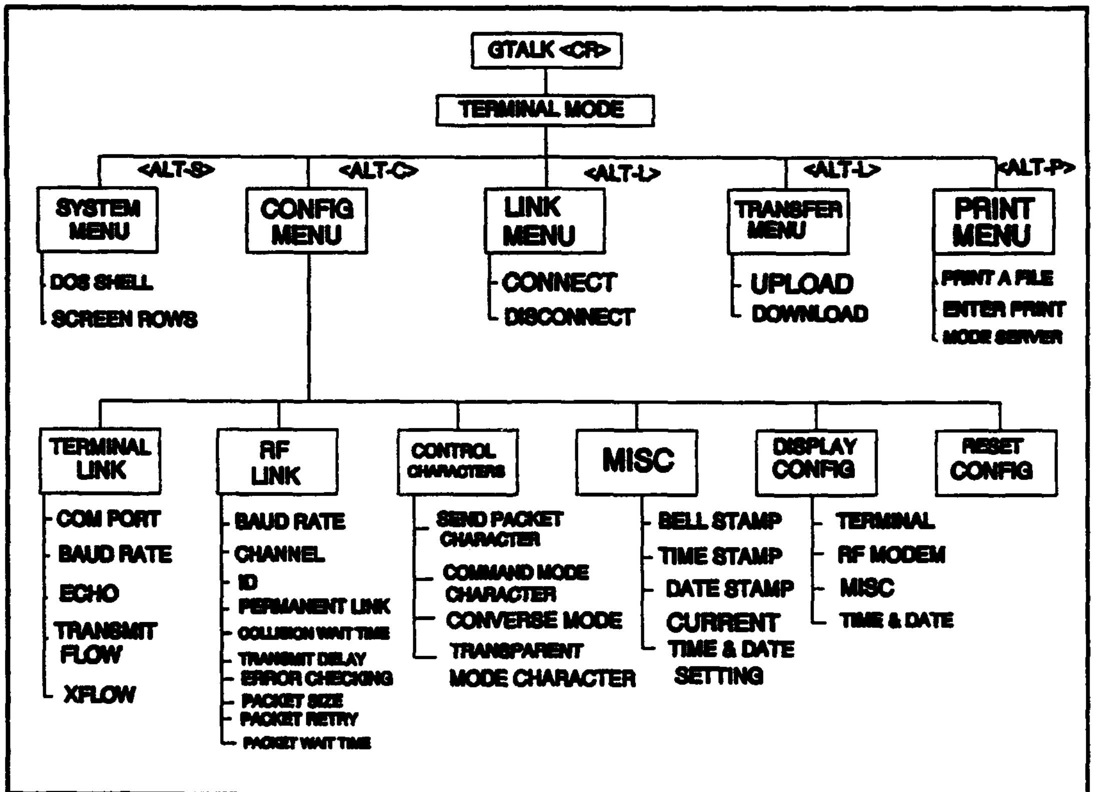


Figure 32. GTALK Menu Flowchart (GINA, 1993, p. 5-1)

[2] A generator polynomial for CRC codes. Specifically CRC-16, where $g(D) = 1 + D^2 + D^{15} + D^{16}$. (Gibson, 1993, p. 359)

TABLE 2. GTALK DISPLAY CONFIGURATION (GINA, 1993, p. 5-13)

Terminal << - >> RF Modem		RF Modem << - >> RF Modem	
COM	COM1	Baud rate	128000
Baud rate	9600	Channel	11
Echo	OFF	ID	1
Transparent flow	OFF	Alternate ID	0
Transmit flow	OFF	Permanent link	OFF
X flow	OFF	Collision wait time	1 X 10 ms
Connection		Transmit delay	5 X 10 ms
0 -> 0 -> 0 ---> 0		Error checking	ON
R1 R2 R3 Dest		Packet size	240
Miscellaneous		Packet retry maximum	10
Bell stamp	ON	Packet wait time	AFTER
Time stamp	ON		10 X 10 ms
Date stamp	ON	Control Characters	
Current time	2:40:41 am	Send packet	13 <CTRL-M>
Current date	1-03-94	Command mode	3 <CTRL-C>
		Converse mode	22 <CTRL-V>
		Transparent mode	20 < CTRL-T>

(ARQ) is used as a backward form of error correction. The frame format consists of one synchronization pulse (at the beginning of each transmission), no start bit, eight data bits (including no parity bit), and one stop bit. This scheme is commonly referred to a "Eight, zero, one and none." It uses an Electronic Industries Association standard EIA-232-D in its level one physical layer. Specifically the GINA uses a serial RS-232-C interface with a DB9 pin connector.

The RS-232 serial data interface will send and receive data asynchronously at rates of 2400, 4800, 9600 and 19.2 kbps. This is the "modem" data rate at which a computer connected to the GINA can transfer data. The GINA will transmit and receive data synchronously, between two different GINAs, at speeds from 16 kbps up to 128 kbps in half duplex. Half duplex means that only one GINA transmits at a time while the other GINA(s) receives. This parameter is known as the "over the air speed". The over the air speed must be greater than the modem speed to permit error correction, i.e., retransmittals or retries, and not allow data buffers in the RS-232-C side to fill and potentially lose data. (GINA, 1993, p. 2-1)

D. ANTENNA DESIGN

The GINA 6000V units were shipped with half wave sleeved dipoles. More efficient antennae had to be designed that would accommodate there intended environments. The Blue Bird needed an antenna that would give an omnidirectional radiation pattern both above and below the horizontal plane of the aircraft. The ground terminal needed an antenna that would give maximum gain at a very low radiation angle (i.e., the horizon), while remaining small, easily portable and moderately priced. A half wave vertical dipole was chosen for the Blue Bird and a double skirted ground plane (DSGP) was chosen for the ground terminal.

A PC-version software program, entitled ELNEC, was used to model both the aircraft and ground terminal antennae before commencing their construction. ELNEC was written by an amateur radio operator Roy W. Lewallen, W7EL. ELNEC is a user friendly program that allows a wide variety of antenna types and parasitic structures to be modelled. Antenna far-field patterns, including gain, can be displayed in various plot and table formats. The ANALYZE feature of the program allows calculation of forward gain, front-to-back ratios, beamwidth and sidelobe levels. ELNEC provides a three-dimensional graphic view of the antenna while displaying currents and superimposed patterns. ELNEC models every antenna as a collection of straight wires. Each wire is divided into segments for analysis purposes. Both antennae were modeled to verify physical dimensions while optimizing radiation pattern, gain, radiation angle and feedpoint impedance. A model of the half wave vertical dipole is shown in Figure 33. The dipole's azimuth plot is shown in Figure 34. A model of the double skirted ground plane is shown in Figure 35. Its associated elevation plot is shown in Figure 36.

1. Blue Bird Antenna

One GINA unit would be mounted in the Blue Bird and would need a antenna mounted exterior to the airframe. A simple half wave dipole mounted vertically would provide an omnidirectional pattern. For simplicity of construction, the dipole was directly feed from a 4 feet length of RG-233U double shielded coaxial cable. Figure 37 shows the antenna consists of two 1/8" brass tubes sleeved into two 3/32" brass tubes and soldered onto a small piece of printed circuit card stock. The concentric sleeved arrangement for each element allows for final "stub" tuning of the antenna when mounted in place on the aircraft. The outer shield of the RG-233U coax was soldered to the upper element and the inner conductor was soldered to the lower element. The coax was fed through a 5/16" brass tube as it left the circuit board. This sleeve served two functions. First, it served as a choke around the outer conductor of the coax to reduce rf current on the shield. This choke action acted in place of a balun to provide a balanced feedpoint. A true balun or coupling transformer would have been ideal but were not used in this design in order to simplify the construction of the antenna thereby minimizing the assembly time. Secondly, the brass sleeve served as a support to attach the antenna to the aircraft fuselage underbelly. The dipole was "cut" for a center operating frequency of 915 MHz. The dipole measuredapproximately 6.14" from end to end. The dipole was mounted vertically aft of the aircraft's rudder. The antenna gain was modeled at 2.13 dBi. The components for the antenna, with the exception of the coax, were available from local hobby and hardware stores for under $10.

2. Ground Terminal Antenna

A suitable ground terminal antenna had to be designed that would have maximum gain at a low radiation angle. The DSGP pictured in Figure 38 is based on a quarter wave sleeved vertical antenna except with two sets of ground radials (i.e., skirts). The DSGP is more efficient than "other" ground plane antennae by virtue of its design to reduce any impressed near field currents below the upper skirt of radials. This action

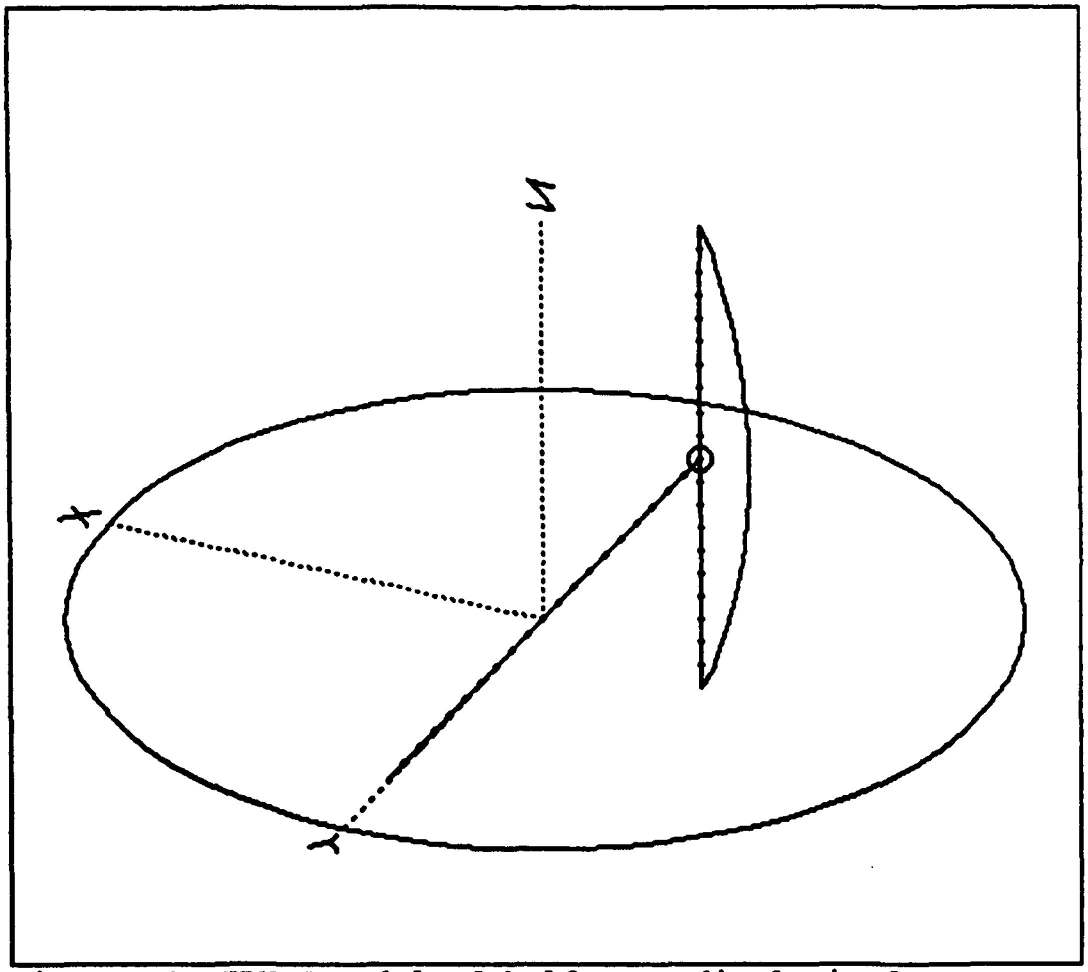


Figure 33. ELNEC model of half wave dipole in free space

also tends to reduce the angle of radiation thereby improving the radiation pattern coverage. The upper skirt radials were drooped to approximately 60 degrees. This step did two things to optimize the antenna performance. Drooping the radials reduced the radiation angle allowing the signal to travel farther toward the horizon without propagating in an upward direction toward the ionosphere and being absorbed as quickly. This also minimized unwanted atmospheric receiver noise. Secondly, drooping the radials lowered the feedpoint impedance to more closely match the impedance of the feedline. This feature minimizes the voltage standing wave ratio (VSWR) and allows maximum

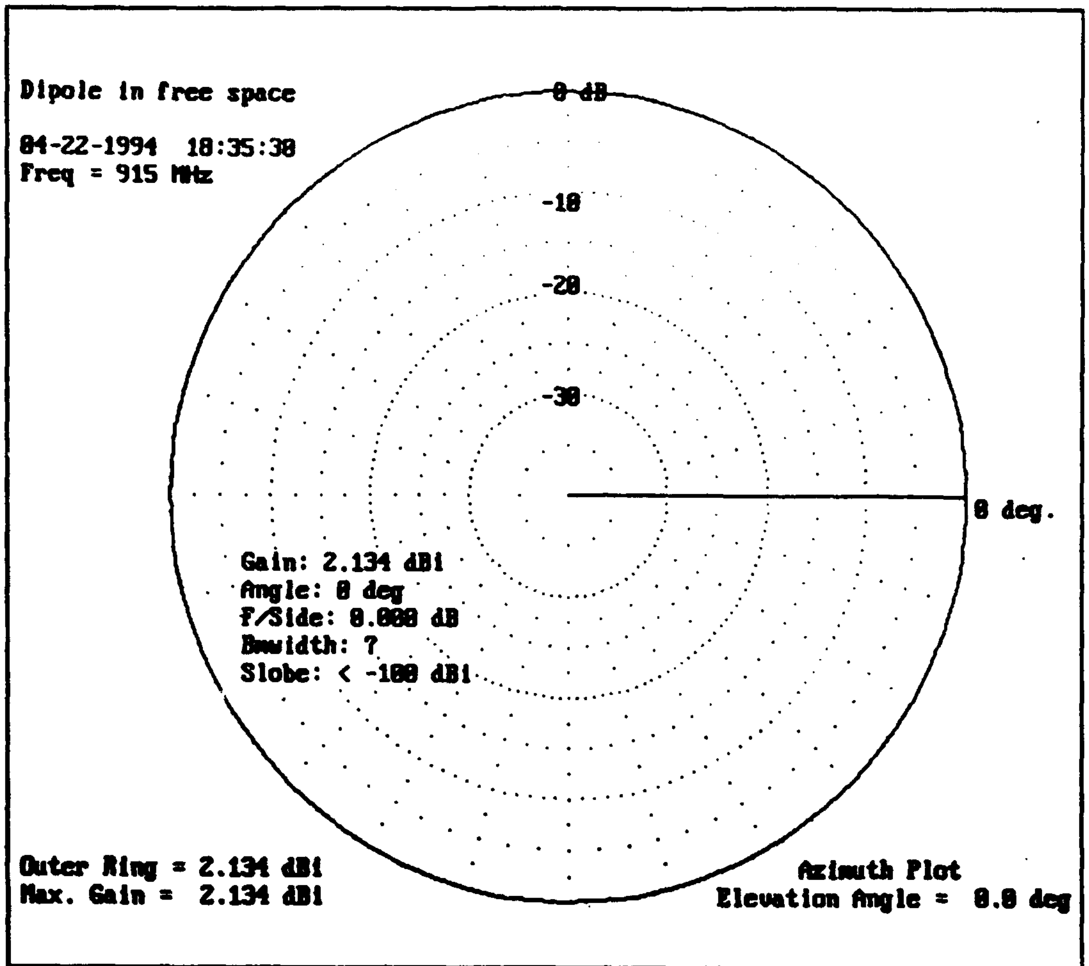


Figure 34. ELNEC model of half wave dipole, azimuth plot

signal transfer between the antenna and the transceiver. The physical dimensions are cut for a center frequency of 305 MHz. The antenna is then operated at the third harmonic (i.e., 915 MHz). This tends to minimize the effects of any stray currents even more since the magnitude of stray currents at the third harmonic are considerably smaller than the stray currents at the fundamental frequency. All ground radials measure a finished 9.2" from the bends. The center vertical element is slightly shorter at 8.7". The antenna gain was modeled at 7.4 dBi. The antenna was mounted on a folding tripod to make it easily portable. The components for the antenna, with the exception of the coax, were available

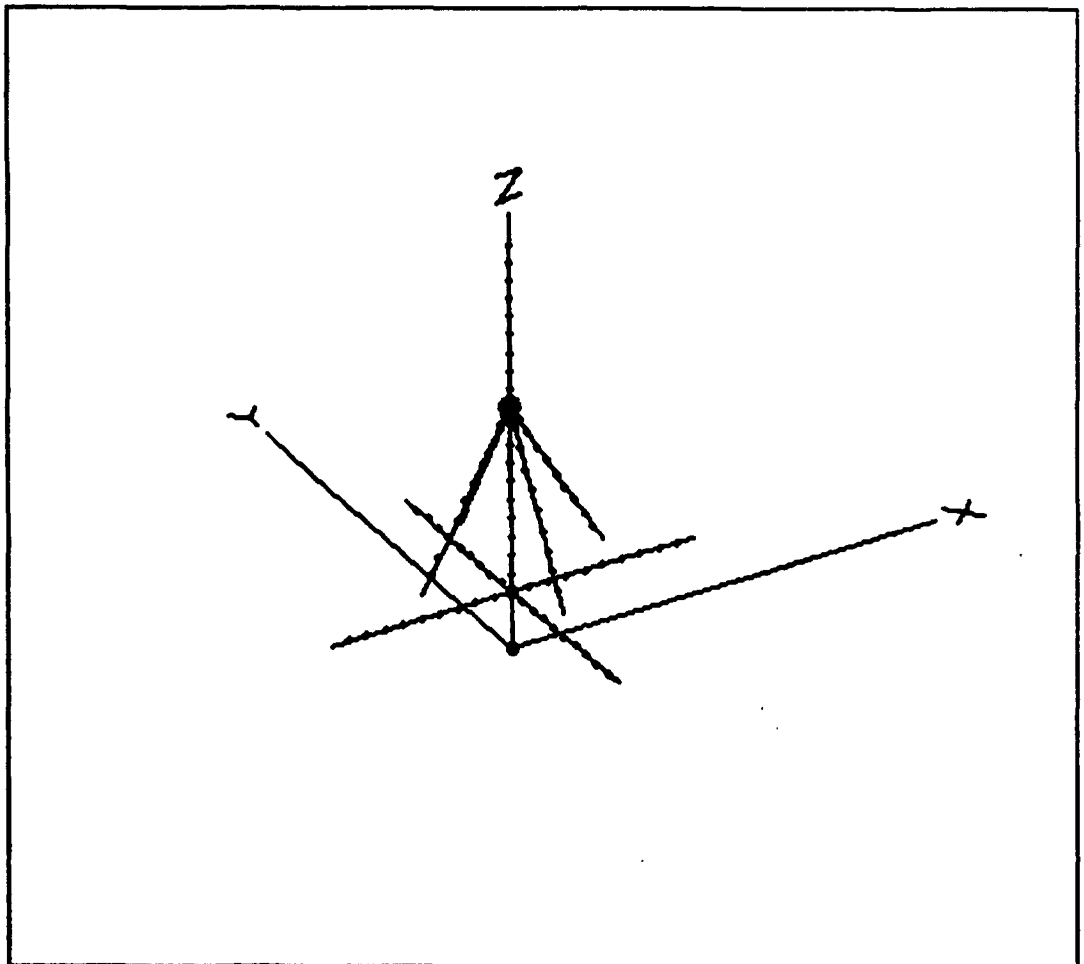


Figure 35. ELNEC model of Double Skirted Ground Plane

from local hardware stores for under $80.

3. Link Budget Analysis

A link budget calculation was made for the manufacturer's stated typical application with stationary units at a maximum distance of 2.5 miles. A second link budget calculation was performed that reflected a worst case actual scenario performed with a flying aircraft at a distance of 2 miles (altitude of 2000' produces a slant range of 2.04 miles). The major degrading factor to this scenario was a 15.0 dB signal pointing loss experienced as the aircraft performed a 45 degree banking maneuver associated with

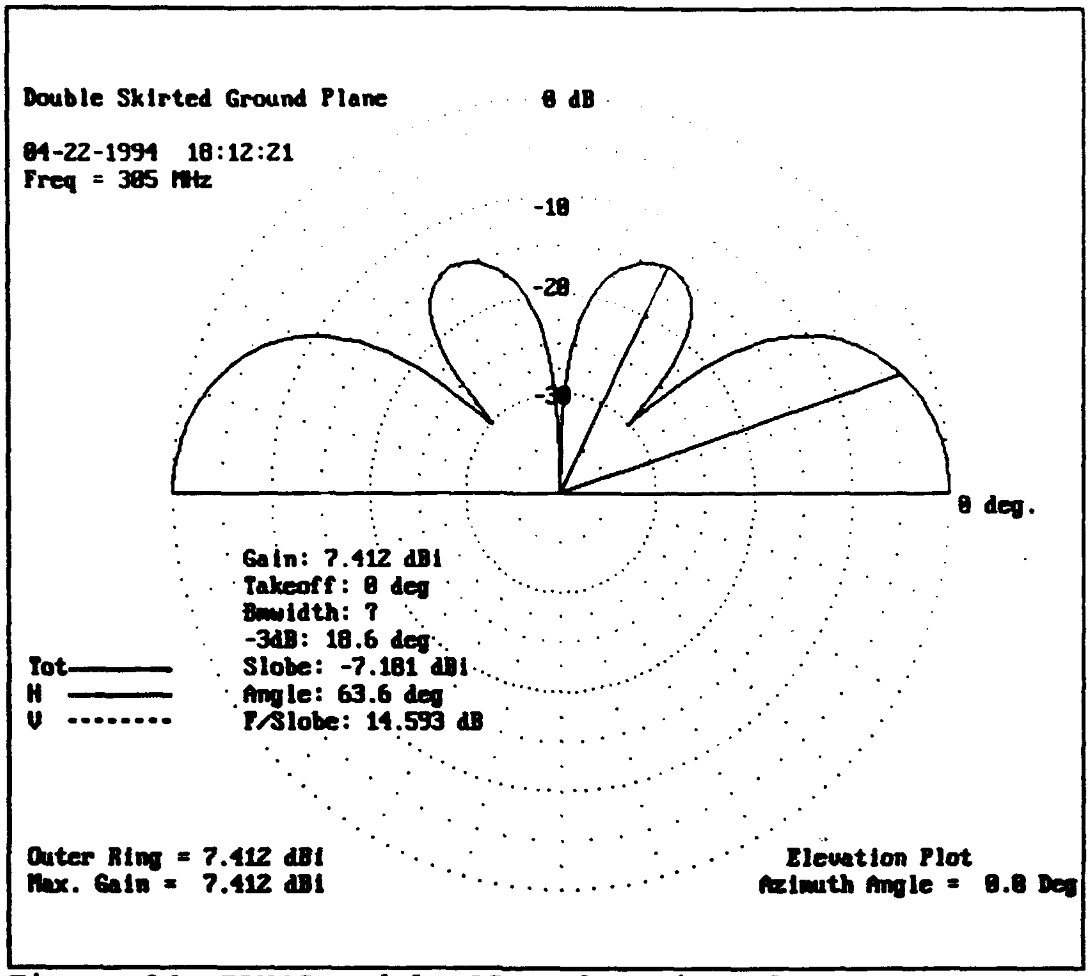


Figure 36. ELNEC model DSGP, elevation plot

a turn[3]. This 15.0 dB pointing loss for 45 degrees of banking assumption is based on previously proven satellite communications experiments that a 90 degree antenna cross polarization would yield 30 dB of pointing loss (Davidoff, 1990, p. 7-7) (Ha, 1990, p. 7). Table 3 summarizes the calculations of the link budget. Disregarding system noise, both the typical static data link application and the intended Blue Bird test flight application have ample signal margins of 33.193 dB and 23.348 dB respectively. Working backwards

[3] Associate Professor Rick Howard, Department of Aeronautics and Astronautics, NPS, stated that 45 degrees would be the maximum bank that the Blue Bird would experience. (Howard, 1994)

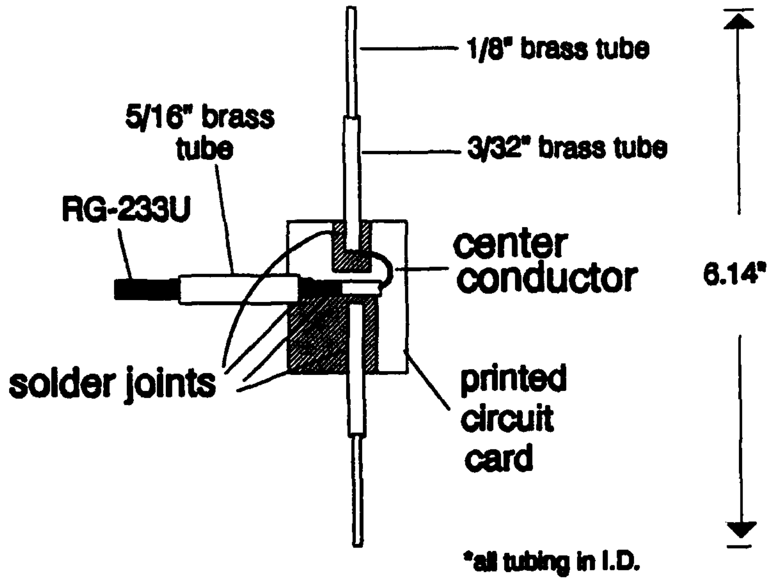


Figure 37. Vertical dipole antenna for Blue Bird

from transmitter EIRP and minimum required receiver signal level, a maximum free space path loss (FSPL) was calculated to be 127.83 dB (Freeman, 1991, p. 210). This allowed the theoretical maximum UAV slant range (without banking) to be calculated.

$$127.83 \text{ dB} = 36.58 + 20 \log D + 20 \log (915)$$

$$D = 39.91 \text{ miles}_{statute}$$

Assuming the UAV experienced a 30 degree bank (i.e., a 10 dB pointing loss), the maximum theoretical slant range would be

$$122.83 \text{ dB} = 36.58 + 20 \log D + 20 \log (915)$$

$$D = 22.44 \text{ miles}_{statute}$$

Assuming the UAV experienced a 45 degree bank (i.e., a 15 dB pointing loss), the maximum theoretical slant range would be

$$112.83\ \mathbf{dB} = 36.58 + 20\ log\ D + 20\ log\ (915)$$

$$D = 7.09\ \text{miles}_{statute}$$

These link budget scenarios suggest that the project criteria of a 40 mile range is potentially achievable if the UAV does not experience a high angle banking maneuver for a period of time greater than the data buffer can accommodate packet retries before data, and potentially the link is lost. The maximum range could be extended if the transmitter power was increased or by using an antenna with a higher gain than the dipole antenna.

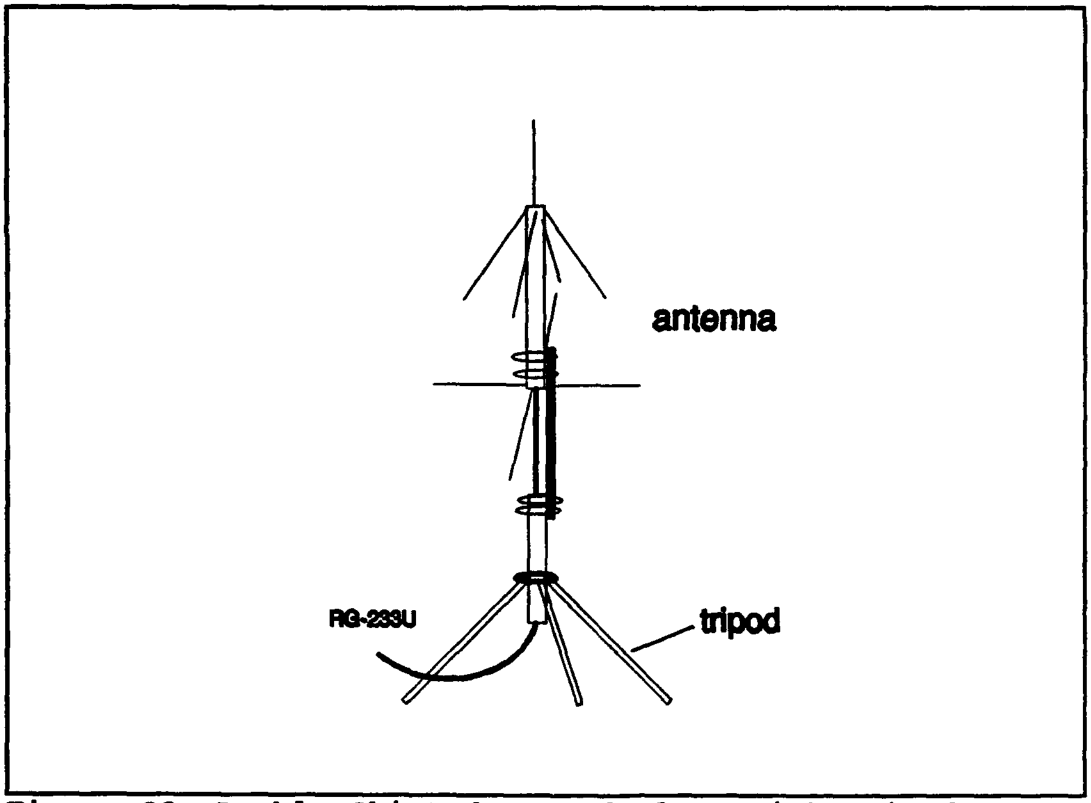


Figure 38. Double Skirted Ground Plane with tripod

TABLE 3. LINK BUDGET

	Typical Application	UAV Application
Frequency (MHz)	915	915
Distance (statute miles)	2.5	2.0355
Transmitter		
Power (dBm)	+ 30	+ 30
Connector loss (dB)	.15	.15
Line loss (dB)	0	.4 (4' RG-233U)
Transmitter antenna gain (dBi)	2.13	2.13
Pointing loss (dB)	0	15.0 (worst case 45 degree bank)
Transmitter EIRP (dBi)	31.98	16.58
Propagation loss (dB)	103.767	101.982
Receiver		
Receiver antenna gain (dBi)	2.13	7.4
Pointing loss (dB)	0	0
Line loss (dB)	0	1.5 (15' RG-233U)
Connector loss (dB)	.15	.15
Carrier power (dB)	-69.807	-79.652
Summary		
Available S/N (dB)	-69.807	-79.652
Required S/N (dB)	-103	-103
Signal Margin (dB)	**33.193**	**23.348**

The formula for processing gain (G_P) is $G_P = R_P / R$. For R = 9600 bps, G_P = 2 MHz / 9600 = 208.333 ⇒ 23.19 dB. The manufacturer lists G_P = 32 dB ⇒ 1584.9 Using the manufacturer's G_P, R = 2 MHz / 1584.9 = 1262 bps. This indicates that the manufacturer's specification will support a 1200 bps data rate. This specification is very realistic.

The number of users is $E_S / N_J = 2G_P / (L - 1)$. From a DS/BPSK pulse noise jammer chart, with ρ = 1.0 and BER = 1×10^{-6}, E_S / N_J = 10.5 dB ⇒ 11.22 (Sklar, 1988, p. 586) L = ((2 * 1584.9) / (11.22)) + 1

L = 283.51 ⇒ 283 users

The manufacturer stated that an arbitrary number of 99 was chosen for the maximum number of users per channel (frequency). This number is very conservative as compared to the calculated number of users. Perhaps, 99 coincides with the maximum number of two digits used for programming in the software configuration menu.

Assuming 0 dB implementations loss, and a BER of 1×10^{-6} (10.5 dB) for a DS/BPSK system with 32 dB of available process gain, the formula

$$J = G_P - (L + E_S / N_J)$$

yields a jamming margin of 21.5 dB. This formula is based on a cw jammer broadcasting across the entire bandwidth of the intended receiver. This value represents an appreciable hurdle to overcome for the potential jammer.

In summary, spread spectrum hardware was selected and procured. Antennae had to be designed and modelled. After the models verified satisfactory designs, the antennae were built from locally available materials. The specifications of the purchased spread spectrum equipment and the antennae served as factors in a link budget calculation. The results of the link budget calculation were assessed to see if the desired UAV range and data link performance was achievable. The link budget indicated that the range and a positive jamming margin were feasible.

VII. TEST AND EVALUATION

This chapter describes the test and evaluation of the data link in two parts, the factory bench test and an actual flight test. The installation of the data link equipment onboard the Blue Bird is reviewed. The preparation for the flight test used to evaluate the data link are discussed. Problems noted in the testing preparation are addressed. The details of the flight test, the data gathered, a description of the data analysis and an evaluation of the data link are presented.

A. FACTORY BENCH TEST

A bench test of a GINA 6000V was observed during a visit to the manufacturer's facility. The test was conducted in five parts. First the transmitter was aligned and the receiver was checked. Then the system was given a 12 hour burn-in. A data throughput test and a data network test was conducted.

To align the transmitter, the RF oscillator was tuned for -10 dBm out at the low (channel 1), middle (channel 11) and high frequency (channel 21), with a spectrum analyzer. Next, the PLL oscillator voltage was adjusted for 5.0 volts DC $\pm$ 1.0 volt with an oscilloscope. Next, the PLL frequency was tuned to 3.7 MHz $\pm$ 2 Hz with a frequency counter. Next, the RF power output was adjusted for 1 watt out into a dummy load with a watt meter and spectrum analyzer for each of the low, middle and high frequencies.

The receiver was checked during the second part of the test. First the receiver sensitivity was tested by using another GINA unit to serve as a generator. The second GINA's output was reduced to - 50 dBm, then attenuated again with a 50 dBm attenuator. The second GINA was used to generate a continuous string of the same character. The signal input level to the GINA under test was now - 100 dBm. The PLL frequency was monitored for lockup (acquisition) with an oscilloscope at the low, mid and high frequencies. The signal level was decreased. To meet the sensitivity specification of -103 dBm, the receiver had to maintain lock with a signal no greater than -103 dBm.

The third portion of the test consisted of final case assembly and a minimum of a 12 hour burn-in followed by another transmit output power test. The fourth portion of the test consisted of a data throughput test. A GINA was placed in a network configuration as an initiating station. The net consisted of the sending station, three repeaters and a receiving unit. The timed test consisted of sending five known file length files through the loop in less than 2 minutes. The fifth portion of the bench test consisted of a final case check for cleanliness, tight screws, sealing, serial number application and packaging. The AC/DC adapters and antennae were tested prior to the final packaging.

B. BLUE BIRD FLIGHT TEST

Prior to the Blue Bird flight test, the vertical half wave dipole was installed on the inside of the aircraft fuselage. The change in antenna location was made after giving considerable thought to the physical protection of the antenna in the event of a tail first landing. A GINA 6000V was mounted inside the aircraft using foam rubber and velcro straps. This step helped minimize the transfer of mechanical vibration from the aircraft to the GINA. Two 6 volt DC gel cells hooked in series were mounted in the plane to provide 12 volts DC power. The DC power circuit to the GINA was passed through an unused set of switch contacts in the Blue Bird's primary radio-control (RC) link. This served as a safety of flight feature to allow the GINA to be disabled should it cause any in-flight interference to the Blue Bird's primary RC flight control system and possibly hazard the aircraft's flight. The transmit data and receive data leads in the RS-232 were jumpered together in the aircraft to provide a loop end around test of the data link. This loop end around test configuration was necessary due to the nonavailability of the onboard computer at the time of the flight test.

On the ground, a laptop computer was connected to another GINA 6000V unit. The ground station GINA was connected to the DSGP antenna. The DSGP would provide omnidirectional coverage with a gain of + 7.4 dBi at a very low angle (at the horizon) of radiation. On the laptop computer, a macro instruction was written to remap received (echoed) lowercase characters to uppercase characters. This detail would allow lowercase characters transmitted from the ground station keyboard, to be saved to a file along with the converted uppercase characters echoed over the data link. At a later time the file would be processed for an equal number of comparisons between lowercase and uppercase characters. For the data link test, the packet size would be set to five characters. Therefore, the stored file should contain five lowercase characters echoed by five uppercase characters.

1. Atmospheric Propagation Path Prediction

Prior to the flight test, an assessment of the existing atmospheric conditions at the test site was performed. Although it was a clear, warm, sunny day at the flight strip, the existence of an ionospheric duct could contaminate the flight test and erroneously skew the test results. The knowledge of the existence of a duct was critical to the interpretation of data link test. If a duct existed, caution to not fly the Blue Bird at altitudes of the duct's lower or upper limits (floor and ceiling respectively) was important. If a duct was penetrated during a data link test, any resulting data error might be attributed to the transition between ionospheric environments rather than the data link performance. The absence of a duct, or the presence of a duct above the intended flight test ceiling of approximately 2000 feet, would not effect data link test.

One hour prior to the flight test, a radiosonde was launched to gather pressure, temperature and relative humidity data. Radiosonde data was disregarded above 10,000 feet since the ceiling of interest was only 2,000 feet. The radiosonde data was used as an input to the Integrated Refractive Effects Prediction System (IREPS). IREPS is a PC-version software package that models a particular communications system in a given atmospheric environment, assesses refractive effects and produces a propagation-conditions summary. (Patterson, 1990, pp. 1-7) IREPS predicted no ducting existed under 10,000 feet. The flight test could now be conducted with altitudes up to 2,000 feet without regard to ionospheric effects.

2. Flight Test

The flight test was conducted at a small airstrip southwest of Hollister, California, and the data was collected. The flight test consisted of flying the Blue Bird at speeds up to about 69 kts (60 mph) and various altitudes. The pilot executed different maneuvers while maintaining a maximum ceiling of 2000 feet. This is currently a requirement of the Federal Aviation Administration (FAA), that all RC aircraft (i.e., the Blue Bird) while in remote radio control, must be maintained in visual range of the pilot. The farthest range traveled by the Blue Bird was approximately 2 statute miles from the ground station. A computer program was written in Ada to make comparisons between the characters and calculate the BER. The algorithm for this program appears in Appendix D. The program was executed and the file characteristics were then computed. The test file characteristics appear in Appendix E.

3. Test Results

During preliminary ground interference testing, prior to the actual flight test, it was observed that the communications system would "lose the link" (acquisition of the signal). This loss of acquisition would occur during engine start-up and at certain engine rpm. The problem was traced to mechanical vibration of the engine coupled to the aircraft, and then imparted to the GINA unit. The mechanical vibration of the GINA caused an oscillator coil on one of the printed circuit cards to vibrate. This physical coil vibration caused its associated oscillator to detune or shift frequency long enough to lose signal synchronization. Even though error detection was active, the storage buffer would fill and the packet retry circuit would eventually time out before the aircraft GINA reacquired the link. This caused a catastrophic loss of data. The problem was remedied by installing resilient shock mounts between the engine and the aircraft. There was no longer any loss of data due to mechanical vibration.

The GINA manufacture stated a BER of 1×10^{-6} for an intended application of two fixed GINA units. Although only one test was conducted, and less than a million characters were transmitted, the observed BER was 7.2411×10^{-6}. Realizing this test was not conducted with two stationary GINAs, as the manufacturer had intended for the application, but between two dynamic points. Specifically, the Blue Bird flew at a speed of 69 kts (60 mph). The manufacturer's stated BER is achievable, even in the dynamic environment of the flying UAV. The entire proof-of-concept data link, including antennae and cabling, was implemented for under $1900. With the GINA 6000V's small size, low weight, low battery power consumption, adequate data throughput and range, commonality of interfaces and low cost, it definitely meets the requirements for the NPS UAV data link.

VIII. CONCLUSIONS

The continual real time update of battlespace information to a warfare commander is critical to mission success. A UAV system can provide this information to the commander and thereby positively effect the commander's ability to influence a battle and bring about the intended outcome. In order to transfer this information product from the UAV to the commander, a data link is required that is both undetectable and jam resistant. Spread spectrum communications can provide this data link. Spread spectrum techniques limit the exploitation of data by unintended parties. This spread spectrum data link has to be interoperable between Services and different systems so that the information products it provides can be easily disseminated and quickly absorbed by the C^2 system. The data link must be COTS technology to achieve the maximum benefit of leading technology while operating within austere fiscal budgets. The GINA 6000V provides a viable COTS solution to link the UAV to the warfare commander.

The GINA 6000V uses a RS-232-D interface. The standard EIA-232-D, which includes the 25 pin RS-232-D interface (and is compatible with the RS-232-C except for its 9 pin connector), specifies an interface which is capable of a data rate of up to 20 kbps with a cable distance of up to 15 meters. The EIA-530 standard, which includes the RS-423-A and RS-422-A interfaces, support significantly higher data rates. The RS-423-A interface specifies unbalanced transmission with data rates from 3 kbps at 1000 meters to 300 kbps at 10 meters. The RS-422-A interface specifies balanced transmission with data rates from 100 kbps at 1200 meters to 10 Mbps at 12 meters. Adopting the RS-422-A interface on both the computer equipment and the spread spectrum data modems would enhance data throughput. (Stallings, 1991, pp. 134-142)

Data compression can significantly improve system performance by increasing throughput and decreasing latency. Specifically in the case of the UAV data link, this could mean increased available bandwidth and reduced queuing delays (e.g., packet retries due to collisions). Even though it takes time to compress and decompress data, compression can nevertheless reduce transmission time because it reduces the amount of data to be sent. Data compression employs sophisticated algorithms to search data for redundancies, which it removes to make the data set smaller. After retransmission, the compressed data is restored to its original form by a complementary decompression algorithm.

> In packet based data compression applications, data must be compressed and recovered in real time without adding substantial latency to data transfers. Windowed protocols allow multiple packets to be outstanding on a link before an acknowledgement is required. Nonwindowed protocols require an acknowledgement to be returned for every packet before the next one can be sent. Therefore every packet incurs a round trip delay. Throughput suffers since the latency associated with each compression and decompression is exposed. In windowed protocols, in contrast, the compression and decompression latencies are able to overlap packet transmission. But even when a windowed protocol such as Transmission Control Protocol / Internet Protocol (TCP/IP) is used, the window size is often not configured to a very large scale. This tends to limit the degree of overlap under high-latency conditions. Due to latency considerations in applications with little or no windowing capability, hardware based compression solutions outperform those based on software or firmware, even when they implement the same algorithm. With a hardware based pipelined compression and transmission architecture, latency may even be negative. In other words, the end of a decompressed packet can arrive at its receiver sooner than it would if it were not compressed. The start of reception for decompressed packets is delayed by the latency of the compression and decompression pipelines. (Weiss, 1993, pp. 36-39)

This delay is more than compensated for a reduction in transmission time resulting form reduced packet sizes. (Weiss, 1993, pp. 36-39)

Data compression would significantly enhance the capabilities of a UAV data link. The increased demand for throughput, particularly in the area of payload data, will be paramount. The transmission of full motion video will be a prime driver. Current data compression technology has permitted near full motion video to be transmitted in a bandwidth of only 112 kbps. Previously, full motion video required an entire T1 channel (i.e., 1.544 Mbps).

"Technology advances and changes in federal regulations are encouraging development of spread spectrum application specific integrated circuits (ASICs)" (Campana, 1993, p. 13). A general purpose low cost spread spectrum module could increase performance in COTS equipment. Although hardware designs will probably follow the demands of the commercial market, slight modifications could be made, when needed, to adapt the ASICs to a particular military application. One such modification could be transmitter frequency. This paper addressed the use of COTS equipment in the ISM band. After proof of concept, a slight modification to the reference clock would permit the transmitter to operate in military allocated frequency bands. Perhaps if the hardware was robust enough, this modification could be accomplished via software changes.

The COTS spread spectrum data link will enhance the role of the UAV in its command and control mission for the warfare commander. The UAV system improves the ability of commanders to more effectively employ their forces in the accomplishment of a mission against enemy forces. The entire proof-of-concept data link was implemented for under $1900. Spread spectrum is the ideal technology to couple the real time missions of the unmanned aerial vehicle to the warfare commander. The virtues of spread spectrum in the area of signal exploitation such as the low noise-like transmitter power density, for low probability of intercept and appreciable receiver processing gain for defense against jamming, are unmatched.

Further research is needed to develop new innovations to the data link such as more capable data interfaces, the use of data compression techniques, and the implementation of ASICs. Further improvements to the data link will contribute to the capabilities of the UAV. These capabilities will continue to enhance the warfare commander's command and control process.

APPENDIX A. GLOSSARY OF TERMS

Asynchronous - Signal pulses not derived from the same reference clock, therefore not having a fixed timing relationship.

Baud - The unit of modulation rate. In binary transmission systems baud and bits per second are synonymous.

Commonality - A quality which applies to material or systems: a) possessing like and interchangeable characteristics enabling each to be utilized, or operated and maintained, by personnel trained on the others without additional specialized training. b) having interchangeable repair parts and/or components. c) applying to consumable items interchangeably equivalent without adjustments. Commonality is a life cycle cost decision. (UAVJPO, 1993, p. 83)

Drone - An unmanned air vehicle which is pre-programmed to conduct a specified mission.

Family - The set of UAV systems that maximizes I&C. (UAVJPO, 1993, p. 83)

Interface - The physical, electrical, environmental, and functional hardware and software requirements, characteristics and constraints that exist at a common boundary between two systems. (UAVJPO, 1993, p. 83)

Interoperability - The ability of systems, units, or forces to provide services to and accept services from other systems, units, or forces and to use the services so exchanged to enable them to operate effectively together. Interoperability is an operational requirement while commonality is a life cycle cost decision. (UAVJPO, 1993, p. 83)

Remotely Piloted Vehicle (RPV) - A nonautonomous UAV, i.e., one that can be controlled through a data link by a human operator. (UAVJPO, 1993, p. 83)

Subsystems - The major elements of a UAV including: the air vehicle, ground control equipment, payload, data link, launch and recovery and logistics support. (UAVJPO, 1993, p. 83)

Synchronous - Signal pulses derived from the same reference clock, therefore having a fixed timing relationship.

Unmanned Aerial Vehicle (UAV) - An aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or non-lethal payload. (UAVJPO, 1993, p. 83)

APPENDIX B. ACRONYMS

AC	Alternating Current
ACAT	Acquisition Category
ACK	Acknowledge
ADT	Air Data Terminal
AGL	Above Ground Level
AJ	Anti Jam
AMSL	Above Mean Sea Level
APE	Autopilot Module
ARPA	Advanced Research Projects Agency
ARQ	Automatic Repeat Request
ASCII	American Standard Code for Information Interchange
ASIC	Application Specific Integrated Circuit
ASN(RD&A)	Assistant Secretary of the Navy (Research, Development & Acquisition)
ATARS	Advanced Tactical Air Reconnaissance System
ATM	Asynchronous Transfer Mode
AVGAS	Aviation Gasoline
BDA	Battle Damage Assessment

BER	Bit Error Rate
bps	Bits Per Second
BPSK	Binary Phase Shift Keying
BHTI	Bell Helicopter, Textron Incorporated
BW	Bandwidth
CALS	Computer-aided Acquisition Logistics Support
CBT	Computer Based Training
CBX	Copilot Control Box
C^2	Command and Control
C^3	Command, Control and Communications
C^3I	Command, Control, Communications and Intelligence
C^4I	Command, Control, Communications, Computers and Intelligence
C^4I^2	Command, Control, Communications, Computers, Intelligence and Interoperability
CDL	Computer Data Link
CDMA	Code Division Multiplex
CEP	Circular Error of Probability
CINC	Commander-In-Chief
COEA	Cost and Operational Effectiveness Analysis

COMINT	Communications Intelligence
CONOPS	Concept of Operations
COTS	Commercial Off The Shelf
CPA	Central Processing Assembly
CPU	Central Processing Unit
CRC	Cyclic Redundancy Check
CR	Close Range
CVBG	Carrier Battle Group
CW	Continuous Wave
DAB	Defense Acquisition Board
DARPA	Defense Acquisition Research Projects Agency (Reduced to simply ARPA under the Clinton administration)
dB	Decibel
dBi	Decibel isotropic
dBm	Decibel per milliwatt
dBw	Decibel per watt
DC	Direct Current
DCU	Diplexer Unit
DEA	Drug Enforcement Administration
DGPS	Differential Global Positioning System
DNL	Downlink
DoD	Department of Defense

DT	Developmental Test
DS	Direct Sequence (Spread Spectrum)
DSGP	Double Skirted Ground Plane
DT&E	Development Test and Evaluation
EAC	Echelons Above Corps
ECM	Electronic Countermeasures
ECCM	Electronic Counter-countermeasures
EDU	Encoder/Decoder Unit
EHF	Extremely High Frequency
EIA	Electronics Industries Association
ELINT	Electronic Intelligence
EMI	Electromagnetic Interference
EO	Electro-optical
EOT	End Of Transmission
EPROM	Erasable Programmable Read Only Memory
EPLRS	Enhanced Position Location Reporting System
EPS	Electronic Power Supply
ESM	Electronic Support Measures
EW	Electronic Warfare
EXCOM	Executive Committee
FAA	Federal Aviation Administration

FCC	Federal Communications Commission
FCS	Flight Control System
FEC	Forward Error Correction
FFH	Fast Frequency Hopping
FH	Frequency Hopping (Spread Spectrum)
FLIR	Forward Looking Infrared
FLET	Forward Line of Enemy Troops
FLOT	Forward Line of Own Troops
FQ&P	Flying Qualities and Performance
FROG	Free Rocket Over Ground (Iraqi Weapon)
FRP	Full Rate Production
FSD	Full Scale Development
FSPL	Free Space Path Loss
GCS	Ground Control Station
GINA	Global Integrated Network Access
GPS	Global Positioning System
GSE	Ground Support Equipment
HDLC	High level Data Link Control
HMMWV	High Mobility Multipurpose Wheeled Vehicle
HUMINT	Human Intelligence
I&C	Interoperability and Commonality

IDL	Interoperable Data Link
IFF	Identification Friend or Foe
ILS	Integrated Logistics Support
IOT&E	Initial Operational Test and Evaluation
IR	Infrared
IREPS	Integrated Refractive Effects Prediction System
JROC	Joint Requirements Oversight Council
JTIDS	Joint Tactical Information Distribution System
JSTARS	Joint Surveillance and Target Attack Radar System
kbps	Kilo Baud Per Second
kg	Kilogram
kHz	Kilo Hertz
KIAS	Knots Indicated Airspeed
kbps	Kilo Baud Per Second
km	Kilometer
kw	Kilowatt
LAN	Local Area Net
lb(s)	Pound(s)
LIC	Low Intensity Conflict
LOS	Line Of Sight

LPD.. Low Probability of Detection

LPE.. Low Probability of Exploitation

LPI.. Low Probability of Intercept

LPR.. Low Probability of Recognition

LPRS.. Position Location Reporting System

LRC.. Lesser Regional Conflict

MAGTF.. Marine Air-Ground Task Force

MAVU.S.. Maritime Vertical Takeoff and Landing Unmanned Aerial Vehicle System

Mbps... Mega Baud Per Second

MEC.. Minimum Essential Capacity

MEF.. Marine Expeditionary Force

MFSK.. M-ary Frequency Shift Keying

MHz.. Mega Hertz

MNS.. Mission Need Statement

MOA... Memorandum of Agreement

MOU... Memorandum of Understanding

MR.. Medium Range

MRC.. Major Regional Contingency

MS... Milestone

MSK.. Minimum Shift Keying

MTI... Moving Target Indicator

NAK.. Negative Acknowledge

NATO.. North Atlantic Treaty Organization

NBC.. Nuclear, Biological and Chemical

NDI.. Nondevelopmental Item

NGFS.. Naval Gunfire Support

nm.. Nautical Mile

NOSC.. Naval Ocean Systems Center

NPL.. Navigational Program Loader

NPS.. Naval Postgraduate School

NSA.. National Security Administration

NVC.. Navigation Control Module

O&M... Operations and Maintenance

ORD... Operational Requirements Document

OSD... Office of the Secretary of Defense

OSI... Open Systems Interconnection

OT.. Operational Test

OT&E... Operational Test and Evaluation

OTH... Over The Horizon

OTH-T.. Over The Horizon Targeting

PC.. Personal Computer

PCM... Pulse Control Modulation

PCS.. Portable Control Station

PEO	Program Executive Officer
PIC	Programmable Interrupt Controller
PIT	Programmable Interval Timer
PLL	Phase Lock Loop
PMTC	Pacific Missile Test Center
PN	Pseudonoise
POM	Program Objective Memorandum
QPSK	Quadrature Phase Shift Keying
RAM	Random Access Memory
RATO	Rocket Assisted Takeoff
RC	Radio Controlled
RCU	Receiver C-band Uplink
RDT&E	Research, Development, Test and Evaluation
RF	Radio Frequency
RH	Return Home
ROC	Required Operational Capability
RPV	Remotely Piloted Vehicle
RRS	Remote Receiving Station
RSTA	Reconnaissance, Surveillance and Target Acquisition
RUU	Receiver UHF Uplink
PCS	Personal Communications Systems

PCS	Portable Control Station
PTT	Push To Talk
RVT	Remote Video Terminal
SAR	Search And Rescue
SBX	Student Control Box
SCADA	Supervisory Control And Data Acquisition
SEAL	Sea Air and Land (U.S. Navy elite team of non-conventional war fighters)
SEW	Space and Electronic Warfare
SFH	Slow Frequency Hopping
SHF	Super High Frequency
SIGINT	Signals Intelligence
SINCGARS	Single Channel Ground Airborne Radio System
sm	Statute Mile
SR	Short Range
SSG	Special Studies Group
SWR	Standing Wave Ratio
TACAN	Tactical Air Navigation
TAF	Tactical Air Force
TAMPS	Tactical Aircraft Mission Planning System
TBMD	Tomahawk Based Missile Defense

TCP/IP.. Transmission Control Protocol / Internet Protocol

TEMP.. Test and Evaluation Master Plan

TDMA.. Time Division Multiple Access

TDRSS.. Tracking and Data Relay Satellite System

TH.. Time Hopping

TM.. Telemetry

TNC.. Terminal Node Controller

TRANSEC.. Transmission Security

TRUS.. Tilt Wing/Rotor UAV System

UAV.. Unmanned Aerial Vehicle

UAV JPO.. Unmanned Aerial Vehicles Joint Project Office

UHF.. Ultra High Frequency

UN.. United Nations

UPL.. Uplink

U.S.A.. United States Army

U.S.A.F.. United States Air Force

U.S.A.R.T.. Universal Synchronous/Asynchronous Receiver/Transmitter

U.S.M.C.. United States Marine Corps

U.S.N .... United States Navy

UTM.. Universal Time Meridian v.......... Volt(s)

VCO.......... Voltage Controlled Oscillator

VHF.......... Very High Frequency

VLC.......... Very Low Cost

VSWR.......... Voltage Standing Wave Ratio

VTOL.......... Vertical Takeoff and Landing

WAN.......... Wide Area Net

APPENDIX C. PIONEER RPV SPECIFICATIONS

1. Dimensions:

   a. Wing span: 16.89 ft (5.15m)

   b. Length: 12.53 ft (3.82m)

   c. Height: 3.4 ft (1.04m)

2. Engine type: Two-stroke, twin cylinder, horizontally opposed, dual carburetor, simultaneously fired, air-cooled.

3. Engine power: 20 kW @ 7,000 rpm

4. Fuel/oil mixture: 50:1 100 octane low lead AVGAS and natural petroleum based oil high quality two-stroke oil BIA certificated for TC-W.

5. Fuel capacity: 11.09 gallons (42 liters)

6. Fuel system: Electric fuel pump and micron filter, overflow fuel line for refueling, and a fuel tank vent line. Single-point grounding system for refueling operations.

7. Electrical:

   a. Minimum battery voltage for takeoff: 32v

   b. Minimum battery voltage in flight: 24v

   c. Generator output: 28v ± 1v

   d. EPS supplies: ± 15v ± 0.25v

      + 5v ± 0.1v

      + 28v ± 4v

8. Communications system:

a. Communication bands: Direct Sequence Spread Spectrum

C-band and UHF for uplink (UPL)

C-band for downlink (DNL)

b. Primary uplink range: 115 miles (185 km)

c. Secondary uplink range: 115 miles (185 km)

d. Downlink range: 115 miles (185 km)

9. Performance characteristics

a. Airspeed limitations:

1. Maximum: Knob control - 95 KIAS

Stick control - 110 KIAS

2. Minimum in still air: 55 KIAS

3. Minimum in rough air: 60 KIAS

4. Stall: 50 KIAS at 381.4 lbs. (173 kg)

52 KIAS at 421.1 lbs. (191 kg)

b. Maneuvering load factors: +3g; -1.5g

c. Weight and balance:

1. Takeoff weight: 448 lbs (203 kg) max

2. Center of gravity: 26.0% - 41.0% MAC

a. Runway takeoff: 32.0% - 37.0% MAC

b. RATO launch: 32.0% - 35.6% MAC

d. Altitude envelope:

1. Service ceiling (Standard Day Rate of Climb 100 ft/min): 15,000 ft

2. Minimum Altitude: Not below radio horizon or elevation of 0° (whichever is higher)

3. Maximum altitude: Line-of-sight angle not greater than 26° above the horizon

e. Roll and pitch angles:

1. Maximum roll: 60° (A/P engaged)

90° (A/P disengaged)

2. Maximum pitch: +18°, -14° (Hold) +16° (Stick)

(A/P engaged), +60° - -60° (A/P disengaged)

f. Wind components: (Takeoff/Landing):

1. Maximum Headwind: 25 KIAS, gusts to 30 knots

2. Maximum Crosswind: 15 KIAS, gusts to 20 knots

10. Environmental requirements

a. Ambient temperature: from 25°F to +125°F (-4°C to 51°C)

b. Rain: up to .24 in/hr (6 mm/hr) over flight path distance of 40 km.

c. Wind: up to 25 knots, with gusts of up to 30 knots

d. Altitude: maximum flight altitude of 15,000 feet with a maximum takeoff/landing altitude of 3,500 feet.

APPENDIX D. BER ALGORITHM

The following program was written in Ada language to evaluate the datalink transmitted test file.

```
-- Title        : BER COUNT FOR DATA PACKET
-- Authors      : Phil Bess and Scott Pratt
-- Date         : 28 November 1993
-- Revised      : 14 December 1993  (2100)
-- Course       : Spread Spectrum UAV Data Link  M.S. Thesis
-- System       : Gateway 2000 486DX/25 MHz
-- Compiler     : Meridian Open Ada 4.1.1
-- Description  :This is a string utility program that will read a
--               text file composed of lowercase characters (LC),
--               followed by a packet echoed back via a data link. The
--               echoed packet characters appear on the file as
--               uppercase (UC) characters. This program outputs
--               the total number of characters in the file, the
--               number of correct comparisons, the number of wrong
--               comparisons, and the bit error rate (BER) of the
--               data stream for an end around data link test.

with TEXT_IO;
use  TEXT_IO;

procedure COUNTBER is

package INTEGER_INOUT is new INTEGER_IO(INTEGER);
use INTEGER_INOUT;

package FLOAT_INOUT is new FLOAT_IO(FLOAT);
use FLOAT_INOUT;

type UPPERCASE is array (1..1000) of INTEGER;
type LOWERCASE is array (1..1000) of INTEGER;

   THE_FILE              : FILE_TYPE;
   UC                    : UPPERCASE;
   LC                    : LOWERCASE;
```

```
  X,Y                    : INTEGER := 1;
  TOTAL_CHARACTERS,
  CORRECT, WRONG              : FLOAT   := 0.0;
  THIS_LETTER,
  LAST_LETTER              : INTEGER  := 32;
  CURRENT_LETTER              : CHARACTER;
  BER                    : FLOAT     := 0.0;

procedure PRINT_HEADER is
begin
  NEW_LINE(2);
  SET_COL(25);
  PUT_LINE("DATA PACKET BER COUNT PROGRAM");
  NEW_LINE;
  SET_COL(10);
  PUT_LINE("This program will read a text file of lowercase and uppercase");
  SET_COL(10);
  PUT_LINE("characters, output the total number of characters in the file,");
  SET_COL(10);
  PUT_LINE("the number of correct comparisons, the number of wrong comparisons,");
  SET_COL(10);
  PUT_LINE("the corrected bit error rate (BER) of the echoed data stream.");
  NEW_LINE;

end PRINT_HEADER;

procedure OPEN_A_FILE(FILE : in out FILE_TYPE) is

  FILE_NAME                : STRING(1..25);
  LENGTH                  : INTEGER;

begin
  SET_COL(20);
  PUT_LINE("Enter the path and file name to process:");
  NEW_LINE;
  SET_COL(35);
  GET_LINE(FILE_NAME,LENGTH);
  OPEN(FILE, MODE => IN_FILE, NAME => FILE_NAME(1..LENGTH));
  NEW_LINE;
end OPEN_A_FILE;

procedure CALCULATE_BER(CORRECT,
                WRONG     : in FLOAT;
```

```
                  BER          : out FLOAT) is

begin

  BER:= 2.0 /(8.0*CORRECT);

end CALCULATE_BER;

procedure PRINT_RESULTS(BER: in FLOAT) is

begin  --(PRINT RESULTS)

  NEW_LINE;
  SET_COL(15);
  PUT("This file has the following characteristics:");
  NEW_LINE(2);
  SET_COL(15);
  PUT("Total number of characters            = ");
  PUT(TOTAL_CHARACTERS,1,4,2);
  NEW_LINE;
  SET_COL(15);
  PUT("Correct comparisons                   = ");
  PUT(CORRECT,1,4,2);
  NEW_LINE;
  SET_COL(15);
  PUT("Wrong comparisons                     = ");PUT(WRONG,1,4,2);
  NEW_LINE;
  SET_COL(15);
  PUT("Corrected packet bit error rate (BER) = ");
  PUT(BER,1,4,2);
  NEW_LINE(4);

end PRINT_RESULTS;

begin   --Begin main program (COUNTBER)
 PRINT_HEADER;
 TOTAL_CHARACTERS:= 0.0;
 OPEN_A_FILE(THE_FILE);
 while not END_OF_FILE(THE_FILE) loop
   GET(THE_FILE,CURRENT_LETTER);
   LAST_LETTER := THIS_LETTER;
   THIS_LETTER:=CHARACTER'POS(CURRENT_LETTER);
   if THIS_LETTER in 65..90 then        -- upper case array
```

```
      UC(X):=THIS_LETTER;
      X:=X+1;
    elsif THIS_LETTER in 97..122 then     -- lower case array
      LC(Y):=THIS_LETTER;
      Y:=Y+1;
    else WRONG := WRONG + 1.0;
    end if;
    if X = 11 then
      for Z in 1..10 loop
       if LC(Z)=UC(Z)+32 then
         CORRECT :=CORRECT + 1.0;
       else
         WRONG:=WRONG + 1.0;
       end if;
      end loop;
      X:=1;
      if Y > 11 then
       for M in 1..(Y-10) loop
         LC(M):=LC(M+10);
       end loop;
       Y:=Y-10;
      else
       Y:=1;
      end if;
      UC := (others => 0);
   end if;
  end loop;
  CLOSE(THE_FILE);
  if X > 1 then
    for Z in 1..(X-1) loop
      if LC(Z)=UC(Z)+32 then
       CORRECT :=CORRECT + 1.0;
      else
       WRONG:=WRONG + 1.0;
      end if;
    end loop;
  end if;
  CALCULATE_BER(CORRECT,WRONG,BER);
  TOTAL_CHARACTERS:= (CORRECT + WRONG);
  PRINT_RESULTS(BER);
end COUNTBER;
```

APPENDIX E. SAMPLE OUTPUT

The following was a sample output from the computer screen when the COUNTBER program was executed.

countber (Running ...)

DATA PACKET BER COUNT PROGRAM

This program will read a text file of lowercase and uppercase characters, output the total number of characters in the file, the number of correct comparisons, the number of wrong comparisons, and the corrected bit error rate (BER) of the echoed data stream.

Enter the path and file name to process:

test1

This file has the following characteristics:

Total number of characters	= 3.4527E+4
Correct comparisons	= 3.4525E+4
Wrong comparisons	= 2.0000E+0
Corrected packet bit error rate(BER)	= 7.2411E-6

Press Enter to Continue

LIST OF REFERENCES

The ARRL Handbook For Radio Amateurs, American Radio Relay League, Newington, Connecticut, 1994.

The ARRL Spread Spectrum Sourcebook, American Radio Relay League, Newington, Connecticut, 1991.

Barnes, Graham, Spread Spectrum: Introduction To Basic Principles and Applications, *IEEE Vehicular Technology Society, Seventh Annual Spread Spectrum Seminar Notes*, Institute of Electronic and Electrical Engineers, Vehicular Technology Society, Santa Clara Valley Section, San Francisco Bay Area Council, June 22, 1993.

Campana, David, and Quinn, Patrick, "Spread Spectrum Communications," *IEEE Potentials*, 0278-6648/93, April 1993.

Coakley, Thomas P., *Command and Control for War and Peace*, National Defense University Press, 1992.

Couch, Leon W., II, *Digital And Analog Communication Systems*, 4th ed., Macmillan Publishing Company, 1993.

Cylink Corporation, *Airlink New Product Announcement*, Cylink Corporation, Sunnyvale, California, June 7, 1993.

Davidoff, Martin, *The Satellite Experimenter's Handbook*, 2nd ed, American Radio Relay League, 1990.

Department of Defense Unmanned Aerial Vehicles Joint Project Office, *Department of Defense Unmanned Aerial Vehicles (UAV) Master Plan 1992*, Washington, D.C., 1992.

Department of Defense Unmanned Aerial Vehicles Joint Project Office, *Department of Defense Unmanned Aerial Vehicles (UAV) Master Plan 1993*, Washington, D.C., 1993.

Dickerson, D.L., Captain, U.S.MC, Wiechmann, J.R., Captain, U.S.MC, Herring, J.G., CW02, U.S.MC, "Pick the Best Unmanned Air Vehicle," *U.S. Naval Institute Proceedings*, v.118/11/1077, November 1992.

Dixon, Robert C., *Spread Spectrum Systems*, 2nd ed., John Wiley and Sons Inc., 1984.

Dixon, Robert C., The Omnipoint PCN Approach, *IEEE Vehicular Technology Society, Seventh Annual Spread Spectrum Seminar Notes*, Institute of Electronic and Electrical Engineers, Vehicular Technology Society, Santa Clara Valley Section, San Francisco Bay Area Council, June 22, 1993.

Eberhardt, Rechtin, The Technology of Command, *National War College Review*, March - April 1984.

Freeman, Roger L., *Telecommunications Transmission Handbook*, 3rd ed., John Wiley and Sons Inc., 1991.

Garrison, L.C., Major, U.S.MC, *Pioneer in the Gulf War*, 3rd ed., Program Executive Officer Cruise Missiles Project and Unmanned Aerial Vehicles Joint Project (PMA-263D1), 15 February 1992.

Gibson, Jerry D., *Principles of Digital and Analog Communications*, 2nd ed., Macmillan Publishing Company, 1993.

GINA New Product Announcement, GRE America, Inc., Belmont, California, March 15, 1993.

Global Integrated Network Access (GINA) User's Manual, Revision 2, GRE America Inc., Belmont, California, 1993.

Ha, Tri T., *Digital Satellite Communications, Second edition*, McGraw-Hill, Inc., 1990.

Howard, Rick, Associate Professor, Department of Aeronautics and Astronautics, Naval Postgraduate School, personal conversation, March 1, 1994.

Joint Chiefs of Staff, *Department of Defense Dictionary of Military and Associated Terms*, Washington, D.C. Government Printing Office, 1 June 1987.

Lawson, Scott, JOSA, U.S.N, "UAV Makes Historic Flight," *All Hands, Magazine of the U.S. Navy*, number 911, February 1993.

Lee, Daniel M., Lieutenant, U.S.N, *Development of a 1/7th Scale Fighter UAV for Flight Research*, M.S. Thesis, Naval Postgraduate School, September 1990.

Lewallen, Roy W., W7EL, *ELNEC*, Beaverton, Oregon, May 3, 1993.

McCune, James A., III, *Pioneer UAV*, Product Update, Pioneer UAV Incorporated, Hunt Valley, Maryland, 4 March 1993.

Photograph by Mr. Don Meeks, Naval Postgraduate School, Monterey, California, Spring 1993.

Military Operations Research Society, *MORS C3IEW MOE II Workshop, Lecture Notes*, Naval Postgraduate School, Monterey, California, 23-25 March 1993.

Nicholson, David L., *Spread Spectrum Signal Design LPE and AJ Systems*, Computer Science Press, 1993.

Orr, George E. , *Combat Operations C^3I: Fundamentals and Interactions*, Air University Press, Maxwell AFB, Alabama, 1983.

Patterson, W.L., *Integrated Refractive Effects Prediction System (IREPS) User's Manual*, Revision PC-2.0, Technical Document 1874, Naval Ocean Systems Center, San Diego, California, August 1990.

Preliminary Technical Manual, "RPV Operation and Maintenance Manual," Pioneer Remotely Piloted Vehicle (RPV) System (Option 2 Configuration), U.S. Navy Contract No. N00019-86-C-0077, Pub. No. 02E-10, Pioneer UAV Inc., 30 September 1990.

Sklar, Bernard, *Digital Communications Fundamentals and Applications*, PTR Prentice-Hall Inc., 1988.

Stallings, William, *Data And Computer Communications*, 3rd ed., Macmilliam Publishing Company, 1991.

Personal interview with Mr. Teru Takahashi and Mr. John Mayeda of GRE America, Incorporated, Belmont, California, November 10, 1993.

Project PENEX, A Polar, Equitorial, Near vertical incidence Experiment, Methodology Document, Draft, Revision 1, Naval Command Control and Surveillance Center, RDTE Division, San Diego, California, 1 July 1993.

Reichert, Frederick W., Jr., Major, U.S. Army, *Data Link Development For The Archytas Vertical Takeoff And Landing Transitional Flight Unmanned Aerial Vehicle*, Naval Postgraduate School Masters Thesis, June 1993.

Technical Manual, "RPV Operation and Maintenance Manual, "Pioneer Remotely Piloted Vehicle (RPV) System, System Description Manual, U.S. Navy Contract No. N00019-86-C-0077, Pub. No. 01-10 Change 1, Pioneer UAV Inc., 1 April 1988.

United States Marine Corps, *Warfighting*, (FMFM1), Department of the Navy, Washington, D.C., 6 March 1989.

Viterbi, Andrew J., "Wireless Digital Communication: A View Based On Three Lessons Learned," *IEEE Communications Magazine*, vol. 29, no. 9, September 1991.

Weiss, Jeffrey, and Schremp, Doug, "Putting Data On A Diet", *IEEE Spectrum Magazine*, vol. 30 no. 8, August 1993.

Witte, Michael J., Commander, U.S. Navy, "Specter...from the Sea," *U.S. Naval Institute Proceedings*, v. 119/7/1085, July 1993.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria VA 22304-6145	2
2.	Library, Code 052 Naval Postgraduate School Monterey CA 93943-5002	2
3.	Director for Command, Control and Communications Systems, Joint Staff Washington D.C. 20318-6000	1
4.	C3 Academic Group, Code CC Naval Postgraduate School Monterey CA 93943-5000	1
5.	Professor Michael K. Shields, Code EC/SL Department of Electrical and Computer Engineering Naval Postgraduate School Monterey CA 93943-5000	2
6.	Professor Michael G. Sovereign, Code OR/SM Department of Operations Research Naval Postgraduate School Monterey CA 93943-5000	4
7.	Professor Rick Howard, Code AA/HO Department of Aeronautics and Astronautics Naval Postgraduate School Monterey CA 93943-5000	1
8.	Professor Isaac Kaminer, Code AA/KA Department of Aeronautics and Astronautics Naval Postgraduate School Monterey CA 93943-5000	1

9. John Mayeda 1
GRE America, Inc.
425 Harbor Blvd
Belmont CA 94002

10. Arthur L. Hoffman 1
Post Office Box 413
Carmel CA 93921

11. Lieutenant Philip K. Bess, USN 4
Post Office Box 5030
Newport RI 02841-5030

12. Fleet Assistance Support Team 2
Marine Corps Support Office
521 9th Street
Naval Air Weapons Station
Point Mugu CA 93042-5010